Volume 6 June, 1927 Number 6

JOURNAL

OF THE

AMERICAN WELDING SOCIETY

Published Monthly by the American Welding Society
33 West Thirty-ninth Street, New York

American Welding Society

OFFICERS FOR 1927-28

F. M. FARMER, *President*
J. H. EDWARDS, *Senior Vice-President*
C. A. MCCUNE, *Treasurer*
M. M. KELLY, *Secretary*
R. L. BROWNE, *Vice-President*
A. M. CANDY, *Vice-President*
STUART PLUMLEY, *Vice-President*
R. L. SHEPHERD, *Vice-President*
G. O. WILSON, *Vice-President*

DIRECTORS

(Officers listed above are also members of the Board of Directors)

Term Expires 1928	*Term Expires* 1929	*Term Expires* 1930	*Section Representatives*
JAMES BURKE	C. A. ADAMS	J. J. CROWE	C. W. BATES
J. W. MEADOWCROFT	A. G. BISSELL	W. H. GIBB	J. C. BENNETT
H. A. WOOFTER	A. E. GAYNOR	H. S. SMITH	H. P. DOUD
S. W. MILLER	H. M. HOBART	W. C. SWIFT	H. D. KELLEY
E. H. EWERTZ	A. G. OEHLER		J. C. LINCOLN
			J. W. MOREISSEY
			D. H. DEYOE
			W. A. SLACK
			ROBERT SIEMER
			F. E. ROGERS

PAST-PRESIDENTS

C. A. ADAMS (1919-20)
J. H. DEPPELER (1920-21)
S. W. MILLER (1921-22)
C. A. MCCUNE (1922-23)
T. F. BARTON (1923-24)
E. H. EWERTZ (1924-25)
A. G. OEHLER (1925-26)

CHAIRMEN, STANDING COMMITTEES

Executive—F. M. FARMER
Finance—C. A. MCCUNE
By-Laws—A. M. CANDY
Meetings and Papers—P. W. SWAIN
Membership—A. G. BISSELL

W. SPRAGEN, *Editor, Journal*

American Bureau of Welding

(RESEARCH DEPARTMENT OF SOCIETY)

OFFICERS

C. A. ADAMS, *Director*
H. L. WHITTEMORE, *1st Vice-Director*
A. D. RISTEEN, *2nd Vice-Director*
WM. SPRAGEN, *Secretary*

CHAIRMEN, RESEARCH COMMITTEES

Welded Rail Joints—G. K. BURGESS
Structural Steel—J. H. EDWARDS
Welding Wire Specifications—C. A. MCCUNE
Pressure Vessels—E. H. EWERTZ

JOURNAL

OF THE

AMERICAN WELDING SOCIETY

Copyright 1927, by the American Welding Society,
33 West Thirty-ninth Street, New York

Subscription $10.00 per year to United States. $11.00 to Canada. Libraries $5.00.
Back numbers, per copy: Members, $0.50; Non members, $1.00.

The Society is not responsible for any statement made or opinion expressed in its publications. Permission is given to reprint any article after its date of publication, provided proper credit is given.

Volume 6 **JUNE, 1927** **Number 6**

TABLE OF CONTENTS

Society and Related Activities

Page

Year Book 3

Training Bulletins 3

News Versus Opinion 3

Safety Codes 4

Past President E. H. Ewertz 5

International Acetylene Meeting 5

Section Activities 6

Technical Papers, Items and Reports

The Welding of the Mokelumne Pipe Line, by Professors L. T. Jones and W. S. Weeks 7

Discussion Mokelumne Pipe Line Paper 27

Welding Research, by C. A. McCune 39

Trend of Fusion Welding Research, by J. R. Dawson 45

Discussion Annual Meeting Papers 47

The Electric Arc, by P. Alexander 62

Current Welding Literature 74

Instructions for Making Thermit Welds (Printed as supplement to June issue)

SECTION OFFICERS AND HEADQUARTERS

PHILADELPHIA

Engineers' Club, 1317 Spruce St., Philadelphia, Pa.

Chairman—R. D. Thomas, R. D. Thomas & Co.
Secretary—H. E. Hopkins, 709 W. Huntington St., Philadelphia, Pa.

CHICAGO

140 S. Dearborn Street, Chicago

Chairman—Ernest Lunn, Pullman Co.
Secretary—Stuart Plumley, Gas Products Assn.

PITTSBURGH

1841 Oliver Bldg., Pittsburgh

Chairman—J. D. Conway, Secretary-Treasurer, Railway Supply Mfg. Assn.
Secretary—H. E. Hollis, P. O. Box 681, Pittsburgh, Pa.

NEW YORK

33 West Thirty-ninth Street, New York

Chairman—F. E. Rogers, Air Reduction Sales Co.
Secretary—A. F. Keogh, Sound Welding Company.

NORTHERN NEW YORK

General Electric Co., Schenectady, N. Y.

Chairman—C. L. Ipsen, General Electric Co.
Secretary—F. S. Peasley, General Electric Co.

CLEVELAND

2200 Chester Avenue, Cleveland, Ohio

Chairman—A. F. Davis, Lincoln Electric Co., Cleveland.
Secretary—O. J. Bornemann, 23 Center Street, Willoughby, Ohio.

SAN FRANCISCO

Rialto Building, San Francisco

Chairman—W. P. Brown, Brown Bros. Welding Co.
Secretary—H. W. Saunders, Air Reduction Sales Co.

LOS ANGELES

420 So. San Pedro Street

Chairman—S. Barton Brown, Barton Brown Engineering Corp.
Secretary—J. Max Lee, Westinghouse Elec. & Mfg. Co

BOSTON

Affiliated Technical Societies of Boston, 715 Tremont Temple, Boston

Chairman—J. A. Shand, Air Reduction Sales Co., Dorchester, Mass.
Secretary—H. P. Peabody, J. A. Roebling's Sons Co.

WESTERN NEW YORK

500 Morgan Bldg., Buffalo, N. Y.

Chairman—Mark Wade, Sr., Oxweld Acetylene Company.
Secretary—G. W. Swan, J. A. Roebling's Sons Company.

DETROIT

149 Larned St. E., Detroit, Mich.

Chairman—W. C. Sprau, Barnes Wire Fence Co.
Secretary—A. W. Fry, C. A. Strelinger Co.

PORTLAND

524 Oregon Building

Chairman—J. S. Beall, Beall Pipe & Tank Corp.
Secretary—Samuel Powell, United Metal Trades Association

AMERICAN WELDING SOCIETY
ESTABLISHED 1919
JOURNAL

Volume 6 JUNE, 1927 Number 6

YEAR BOOK

As has been the custom in the past, the Annual Year Book of the American Welding Society will be published as the August issue. The Membership Committee respectfully urges every member of the Society to secure at least one new member on or before July 1, in order that this year's Directory may show a substantial increase of members over that of 1926. In order to aid members of the Society in this membership work, copy of the 1926 Year Book will be mailed upon request to anyone desiring same. The growth of the American Welding Society is entirely dependent upon the support it receives from its members. Joining the American Welding Society implies greater obligations than mere payment of dues. It requires an active participation in the affairs of the Society including its membership activities.

TRAINING BULLETINS

The Educational Committee of the American Welding Society has prepared training courses for electric arc, gas, resistance and thermit welders. These courses have been edited by Mr. J. C. Wright of the Federal Board of Vocational Education.

Owing to the enormous cost of printing, no solution was found until recently for financing the publication of these courses. The Society announces with pleasure that the first of these courses on Thermit Welding is printed as a Supplement to this issue of the Journal. A number of copies will be run off and bound in separate bulletin form. These may be obtained at fifty cents per copy. The other courses will appear at the rate of one per month as supplements to the regular issue of the Journal. Orders may be placed in advance for any or all courses at fifty cents per copy. When they are all printed, a number of the four courses will be bound in attractive book form and made available to the members at $3 per copy.

WELDING PIPE JOINTS

(Reprinted from May 3, 1927, issue "Power.")

The question of joints in the pipe lines of the modern central station is becoming increasingly important as temperatures, pressures and pipe sizes increase. The cost of the ordinary flange joint under these conditions makes welded joints seem exceedingly attractive. On the other hand, the uncertainty of the character of the weld, the difficulty of detecting defects and the dependence placed on the human element are factors which many engineers believe act against the adoption of welded joints. Considering the low stresses existing in well designed pipe lines, these fears may be too conservative, as it is evident that a number of minor defects could exist in the welded joint of a large pipe without seriously increasing the stresses in the more perfectly welded parts.

Although welding steam pipes is comparatively new to central stations, one station has used welded joints for all its piping including high-pressure steam mains, and others are employing it to a lesser degree. From the somewhat greater experience of oil refineries with this type of joint the central station engineer may obtain considerable of value.

Careful training of men, constant supervision and continued improvement in methods and equipment may be expected to result in the elimination of welding defects.

NEWS VERSUS OPINION

(Reprinted from March 31, 1927, issue Engineering News Record.")

It is the custom of societies to place in a prominent position in their printed proceedings some such notice as this: "The society is not responsi-

ble as a body for the opinions and statements advanced in this publication." Periodicals do not go to such lengths to avoid responsibility, mainly because such a statement will not remove responsibility, either as to fact or opinion, when the article is unsigned, and will not remove legal responsibility if by chance a signed article is libelous. Nevertheless there are certain distinctions between opinion and fact in the columns of any well run journal which sometimes are not understood. Charles A. Dana once told an indignant correspondent that anything that the good God allowed to happen was fit subject for the columns of the *Sun*. Whether the editor believed that the happening was unfortunate or ill-advised or one which he, if permitted deistic control, would not have allowed was beside the point. It happened—and therefore the *Sun* printed it. It is obvious that an editor would have difficulty in maintaining this viewpoint. Some things do happen that no one writes about. But by and large the Dana principle is a good one. News is what occurs and the reporting of news is the reporting of what occurs.

In the mass of many things that occur there are only some that are of interest to the reader, and editorial judgment must be exercised in their selection. But beyond that the editor cannot pass judgment on the propriety of the happening. To refuse to print the news of something that happened and is known to a number of people because that happening may have an adverse effect on certain people is to fail in the true reportorial function. This is an elementary statement of a journalistic axiom, but apparently all readers do not understand it. They confuse a news report with editorial comment and sometimes believe that because a paper reports someone as saying something, that editorial assent is given to what is said; that because certain devices fail, to report that failure is to condemn the device. The news lies in the fact and if the fact exists the news must be reported. Opinion as to that fact is never properly given in the report but is left for inclusion in another part of the paper where the responsibility of the editor is clearly evident. If the reader of news keeps this distinction in mind he will never be misled by a news report.

SAFETY CODES

A committee of the American Welding Society, appointed to study the problem of the formulation of a welding code governing the safe practices to be used in this industry, recently recommended the endorsement of a number of existing safety codes. It was felt that enough codes and regulations were in existence governing the welding industry. The Executive Committee of the Society, believing the safety codes listed below to be in accordance with good practice, recommends their adoption.

1. The National Electric Code. To be followed in the installation of electric welding equipment. Latest copy of this code may be obtained from the National Board of Fire Underwriters.

2. Rules of the National Board of Fire Underwriters 1926 or subsequent editions, entitled "Regulations for the Installation and Operation of Gas Systems for Welding and Cutting." Copies may be obtained from the National Board of Fire Underwriters, 207 East Ohio Street, Chicago, Ill.

3. "Standards for Construction and Performance of Stationary Automatic Acetylene Generators for Oxy-Acetylene Welding and Cutting Systems," prepared by the Underwriters' Laboratories of the National Board of Fire Underwriters, 207 East Ohio Street, Chicago, Ill. These specifications constitute an outline of the requirements for the construction and performance of stationary automatic acetylene generators for oxy-acetylene welding and cutting for installation in outside generator houses or inside generator rooms in accordance with regulations of the National Board of Fire Underwriters for the Installation and Operation of Gas Systems for Welding and Cutting. These rules specify minimum requirements.

4. "The National Safety Code for the Protection of the Heads and Eyes of Industrial Workers," published as No. 2 of the handbook series of the Bureau of Standards, Washington, D. C. This document gives specific recommendations as to the construction of goggles and their lenses that should be used by workmen employed in the electric and gas welding industry.

5. Bulletin No. 9 of the Bureau of Explosives, 30 Vesey Street, New York, in so far as it relates to the construction of cylinders for containing compressed gases, and regulations in the matter of charging and

marking cylinders containing compressed gases, if such cylinders are to be handled by a carrier engaged in interstate commerce business.

6. Bulletin No. 23 issued by the National Safety Council, 168 N. Michigan Avenue, Chicago, Ill., entitled "Safe Practices, Gas and Electric Welding." This pamphlet is a presentation of accident hazards in gas and electric welding and the best practice for their elimination.

PAST PRESIDENT E. H. EWERTZ OPENS CONSULTING ENGINEERING OFFICE

Mr. E. H. Ewertz, one of the founders of the American Welding Society and a past president, has left his position as general manager of the Moore Plant of the Bethlehem Shipbuilding Corporation to open up independent consulting engineering offices at 50 Church Street.

Mr. Ewertz, for a number of years, has recognized the possibilities of welding and has been one of the most enthusiastic supporters of welding, and in his new work will make a specialty of the applications of and proper use of welding in manufacturing, general engineering and structural work. In this capacity, he will be able to bring to bear his wide engineering and management experience in the solution of problems requiring a study from the point of view of utilizing welding and proper management in the reduction of cost of products, improvement of quality and the adaptation of other manufacturing methods.

Mr. Ewertz has had thirty years' experience in the engineering field including management of plants employing 9000 men. Among the companies with which he has been connected may be included the navy yard in Sweden, Schwartzcoph Machinery Co., Berlin, Germany; Gardner & Coe, New York; Roach Shipbuilding Co.; Chester Crescent Shipbuilding Co., Elizabeth; U. S. Shipbuilding Co., Elizabeth; Victor Metals Company, the Fore River Shipbuilding Company, Bethlehem Shipbuilding Company, Bethlehem Steel Company, Electrical Boat Company. This experience in addition to shipbuilding covers construction and design of machinery and parts and the organization of one of the most successful war fabrication plants.

MANUAL OF ENDURANCE OF METALS UNDER REPEATED STRESS

Heretofore popularly called

FATIGUE OF METALS

A little book for the practical use of Designing, Inspecting, Testing and Operating Engineers. Compiled at the request of Engineering Foundation.

By H. F. MOORE, D.Sc.,

Research Professor of Engineering Materials, In Charge, Investigation of Fatigue of Metals, University of Illinois.

With the cooperation of the directors of other important investigations in this field.

In 60 pages of clear statements, tables and diagrams, Professor Moore has condensed much of the usable information gotten by researches occupying several years of work by a score or more of investigators and many advisers, and costing in the aggregate a few hundred thousand dollars.

Bound in cloth, with stiff boards, 5 x 7 inches.

Price $1.00 Postpaid

Orders and remittances should be sent to

ENGINEERING FOUNDATION
29 WEST 39TH ST., NEW YORK

INTERNATIONAL ACETYLENE AND WELDING MEETING

The Ninth International Acetylene and Welding and Allied Industries Congress will be held in Bruxelles from the 5th to the 8th of July, 1927. The permanent international committee has been intrusted to report before this congress on an international inquiry regarding the present state and condition of these industries throughout the world.

Thinking that this questionnaire may be of interest to our readers, it is reproduced below.

INTERNATIONAL INQUIRY QUESTIONNAIRE

Carbide Calcium: Consumption in 1926? State, if possible, the respective quantities consumed for fixed lighting plants, portable lighting, autogenous welding and cutting.

How many carbide manufacturing plants? If possible, a list of factories.

Oxygen: Total consumption in 1926? How many producing plants and list of factories, stating, if possible, which use the liquefaction process and which the electrolytic process?

Dissolved Acetylene: Consumption in 1926? Number and list of producing plants? State, if possible, the quantities used for lighting and for welding.

Acetylene Lighting: Condition of lighting in 1926? Fixed and portable lighting: portable lamps, miners' lamps, railway lamps, signalling, lighthouses, fishing, etc.

Autogenous Welding: Condition and development of welding: acetylene generators (percentage of different types), torches, reducing valves, accessories, filler rods and fluxes. Notes on principal work performed: construction and repair. Note on the development of electric arc welding.

Training and Propaganda: Is the teaching of welding organized in your country? Is welding taught in technical and industrial schools? How is this teaching carried out?

Chemical Derivatives of Acetylene: Can you give us some information as to the chemical derivatives of acetylene, their manufacture, their importance as represented by the quantity of carbide used, a list of the principal products thus manufactured?

SECTION ACTIVITIES

Boston

On May 18 a meeting was held in conjunction with the Lynn Section of the American Institute of Electrical Engineers. The subject was "Arc Welding." The speakers of the evening were Prof. C. A. Adams, Mr. H. M. Hobart and Mr. P. P. Alexander. This was a very interesting meeting and was well attended.

Philadelphia

The Philadelphia Section held its May meeting on the 16th in the Engineers Club Auditorium. Mr. Carl J. Holslag delivered a talk on "Welding of Houses and Buildings."

Pittsburgh

A successful meeting was held on May 20. Mr. W. R. Hulbert and Mr. H. D. Kelley of the Metal & Thermit Corporation presented a paper on "Recent Improved Methods for Welding with Thermit." This paper was illustrated with lantern slides and demonstrations.

New York

The New York Section held a joint meeting with the Metropolitan Section of the American Society of Mechanical Engineers on May 17. This meeting was one of the most successful of the season, having over 300 people present. Prof. L. T. Jones of the University of California presented a paper on "The Welding of the Mokelumne Pipe Line." which was illustratd by lantern slides. This paper was written by Professors L. T. Jones and W. S. Weeks. The paper was discussed by a number of prominent engineers.

Western New York

This Section held its May meeting on the 17th. Mr. L. J. Sforzini of the Eastman Kodak Company presented a paper comparing riveted and welded joints, pointing out the advantages and disadvantages of both riveted and welded joints; giving examples of actual welded plate jobs. shop fabricated, pointing out in each case why welding was used. He described two large welded field jobs including difficulties encountered and how they were overcome. This paper was illustrated by slides.

San Francisco

The regular monthly meeting of the San Francisco Section was held on May 20. Mr. W. F. Barron of the Linde Air Products presented a paper on "Dependability in Structural Welding." The American Brass Co. showed a very interesting and instructive motion picture entitled "The Story of the Anaconda."

EMPLOYMENT SERVICE BULLETIN

POSITIONS VACANT

V-38. We wish to get in touch with several Electric Arc Welders who have experience in structural steel welding and are good on overhead work. Only men experienced in welding and in field structural work wanted.

The Welding of the Mokelumne Pipe Line*

LLOYD T. JONES† AND WALTER S. WEEKS††

Members of the American Welding Society, The American Society of Mechanical Engineers and friends; I have the honor and the pleasure of presenting the results of a detailed study of the acetylene welding of the Mokelumne Pipe Line. I shall endeavor to make the picture complete in order that you may judge for yourselves the sufficiency of the changes recommended and that slight though these changes seem to be you may see their necessity.

The investigation by Prof. Walter S. Weeks and me was carried out at the request of the Board of Directors of the East Bay Municipal Utility District and A. P. Davis, their chief engineer.

The cities lying on the east side of San Francisco Bay have formed the East Bay Municipal Utility District for the purpose of bringing water some ninety miles from the Mokelumne river to the reservoirs at Berkeley and Oakland. Fig. 1 shows the location of the aqueduct. The water from the dam at the Mokelumne river will be carried through about eighty miles of 65 inch steel pipe across the San Joaquin river to the edge of the Berkeley Hills and thence through cement lined tunnels to the reservoirs. The extreme danger of a water famine made it imperative that additional water be available at the close of the rainy season of 1926-27. The rainy season is just now over. Accordingly the steel line was begun at the San Joaquin river and proceeded toward Berkeley, in order that temporarily water might be taken from the San Joaquin river if necessary.

Acetylene welding of the girth welds of the line began during the early spring months of 1926. The usual welding process, with the single V and low-carbon welding rod, was employed. The welding was accomplished entirely from the outside. Difficulties with breakage were encountered almost immediately, of the first one hundred girth welds 5.5 per cent of the welding footage failed. One weld was completely broken.

As an immediate remedy an electric metal-arc weld was placed on the inside of the girth weld. This involved the added difficulty of chipping away the protruding metal before the electric weld could be placed. It was thus necessary to procure and handle both compressed air equipment and electric welding equipment in addition to that already in the field. It is true that not a single electrically-backed-up weld has broken during the construction of the line, but as a production process it is expensive.

Some twenty-five thousand linear feet of the line were thus constructed and subjected to the 200 lb. per sq. in. water pressure

---

* Presented at joint meeting of the Metropolitan Sections of the A. S. M. E. and A. W. S., May, 1927.

† Asst. Prof. Department of Physics, University of California.
†† Associate Prof. Department of Mining, University of California.

with nearly zero leakage. As a further guard against operating stresses not yet encountered the girth welds were provided with five butt straps each, electrically welded across the acetylene welds. There remained, however, the question, "Why did acetylene welding fail when it is so eminently satisfactory on small pipe lines and what changes can be made to make it satisfactory on large lines?" It is in answer to this question that I present this paper for your consideration.

The ditching machine, Fig. 2, was required to dig a ditch about seven feet wide and nearly ten feet deep in order that the steel pipe might be carried below existing irrigation systems. The ditcher is shown passing through sandy soil that is caving badly

Fig. 1. Map showing location of Mokelumne pipe line (dotted line)

immediately behind it. After the pipe was placed in the ditch by the crane, Fig. 3, it was held in alinement by a system of wedge shaped keys and slotted plates, Fig. 3a. Longitudinally they were held in position by short welds which I have chosen to call "retaining welds." Fifteen to twenty-five pipe sections, each thirty feet long, were laid and welded each day. Immediately after welding, the middle of each section was back-filled, the welds being left exposed for subsequent tarring and wrapping. The condition of the pipe as it lay in the ditch is shown in Fig. 4. Fig. 5 shows the appearance after backfilling.

Since most of the difficulties of construction encountered were due to expansion under the action of the sun and to the consequent contraction during the night it may be well to acquaint ourselves with the temperatures involved, both the temperature of the air and that of the metal of the pipe exposed to the sun. Fig. 6 shows air temperatures and also temperatures of the top and of the bottom of the pipe as it lay ready for welding. It will be observed that there is a large differential temperature, nearly 50 deg. F.,

between the top and bottom of the pipe during the middle of the day. Will you also note that during a large part of the night the temperatures of top and bottom are almost exactly equal?

One of the aggravating consequences of the sun's heat was the daily motion of the free end of the line under construction. Each forenoon the pipe lengthened a few inches and contracted a like amount during the late afternoon and evening. The backfilling functions both by controlling temperature and by placing a heavy load on the pipe. A quarter of a mile of partially backfilled pipe moves back and forth each day and it is readily seen that the twenty or more sections that are in position ready for welding must be provided with retaining welds sufficient to either push or pull the whole group.

Fig. 2. The ditching machine passing through sandy soil

The amplitude of motion of the free end of this particular pipe may be represented by cT^2 where T is the temperature range of the top of the pipe and c is a constant whose value depends on the constants of the metal of the pipe, the size and thickness of the pipe and the load per linear foot due to the dirt covering. I shall not burden you with a derivation of this equation. Its derivation is included in our completed study now in course of publication[1]. The validity of the equation is indicated by the comparison of observed and calculated values shown in Fig. 7. A study of the motion of the pipe was necessary in order to arrive at conclusions regarding the stresses encountered. A recording motion meter was devised which gave a continuous record of motion of the pipe.

All motion of the pipe acts as a relief for stress. Indeed if

1. University of California Publications in Engineering, Manager University Press, Berkeley, California.

motion were entirely unrestricted, either by the load on the pipe or by the metal itself no stress could result. If the pipe be so locked in position that no motion can result the stresses may be calculated directly from the temperatures involved.

Stresses in the pipe line were measured at many points both at the top of the pipe and at the bottom. The method of measuring stress is indicated in Fig. 8. A bar of the same steel as the pipe was laid along the pipe and so protected that its temperature was constantly identical with that of the pipe. This bar was fastened to the pipe at only one end. A microscope comparator at the opposite end served to detect and measure relative movement between that end of the bar and the pipe. This movement was direct-

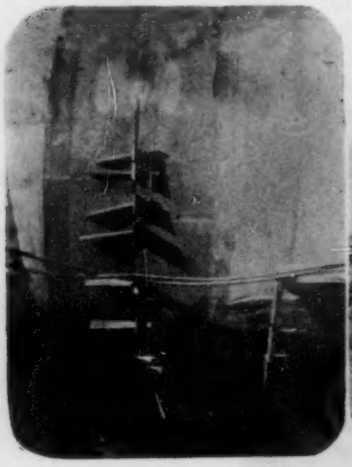


Fig. 3 (below). The crane used to handle the five-ton pipe sections

Fig. 3a (left). The pipe sections are held in alinement by keys.

ly proportional to the stress and independent of the causes of the stress. The comparator was later replaced by a recording device which gave a continuous record of the stress. Fig. 9 shows the recorder in action.

The stresses involved in the construction and operation of a pipe line are many and their relations are not always simple. It may facilitate discussion somewhat if we divide them into two groups:

	Probable values, 16/in.²	
	Tangential	Longitudinal
A. Operating Stresses.		
Water-pressure stress	13,000	6500*
Cold-water stress	.....	5000
Poisson stress	.....	3250
B. Constructional Stresses.		
Residual welding stress	.....	....
Shearing stress	.....	....
Gravitational	.....	....
Differential-temperature stress	.....	9000
Line stress	.....	8400

* Found only at closed end of line.

Operating Stresses

Because of their relative simplicity the operating stresses are placed first. Operating stresses are mechanical stresses involved in the normal operation of the line.

Water-pressure stress

By water-pressure stress I shall mean the tangential fiber stress due to the hydrostatic pressure within the pipe. For 200 lb. per

Fig. 4. General appearance of the pipe line during welding.

sq. in. in the 65 in. x ½ in. steel pipe of the Mokelumne line the fiber stress will be 13,000 lb./in.^{2} as calculated by the equation

$$F = \frac{RP}{t}$$

where R is the radius of the pipe, t the thickness of the metal and P the water pressure. The value is approximately half the elastic limit of the metal.

There is another stress due to water pressure that is sometimes found and which is frequently overlooked in pipe line work. I refer to the longitudinal tension caused by pressure on the end of a closed line undergoing test. This tension is of course greatest at the closed end and is negligible a few hundred feet away from the end. At the end the weld nearest the test head is thus subjected to an extra tension of 6500 lb./in.^{2}. This figure is for the Mokelumne line, during the time it is under test.

Cold-water stress

Several miles of the particular pipe line under discussion were completed with the temperature of the metal of the pipe never

at any time falling below 65 deg. F. Later it will be called upon to carry water at a temperature of about 40 deg. F. This drop of 25 deg. F. in temperature will then cause a longitudinal tension of 5000 lb./in.^{2} which the line has not yet been called upon to stand.

Fig. 5. The preliminary back-fill left the welds exposed for inspection during pressure tests

It was primarily to guard against this stress that the electrically welded butt straps were placed across the acetylene welds.

Poisson stress

The presence and importance of Poisson stress seem to have never been brought to the attention of those interested in pipe line construction.

Poisson has shown that if a stress F be applied in one direction there will be an accompanying deformation equivalent to a stress σ F in the direction at right angles. The value σ, known as Poisson's ratio, is a constant dependent on the nature of the material. We have measured the value of this constant for this particular pipe line by measuring the longitudinal deformation of a single pipe section undergoing hydrostatic pressure test. While our result at low stress showed a departure from the accepted value it nevertheless approached the accepted value of 0.25 for the pressures to which the line will be subjected while in operation. A tangential fiber stress of 13,000 lb. per sq. in. due to operation of

the line under its normal water pressure will thus cause a longitudinal tension of one quarter this amount, 3250 lb./in.² in a locked line.

Remembering this inherent 5000 lb./in.² cold-water stress and

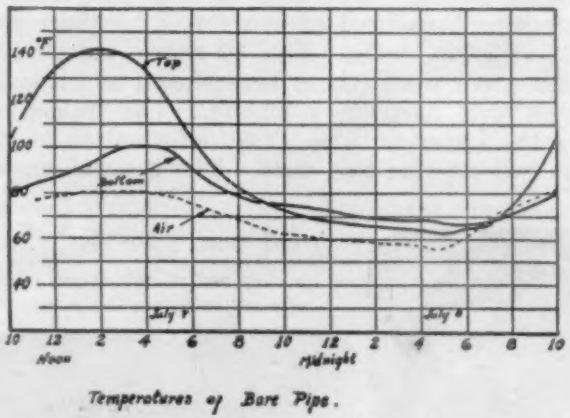


Fig. 6. The temperatures of the air, the top of the pipe and the bottom of the pipe during a typical summer day

MOVEMENT OF PIPE

Joints from free end	Measured inches	Calculated inches
0	1.03	1.03
10	0.58	0.58
20	0.24	0.26
30	0.11	0.064

Fig. 7. The validity of the motion equation is indicated by comparison of calculated and observed values

the 3250 lb./in.² Poisson stress it behooves us then to construct the line with as little residual tension as possible.

Constructional Stresses

The constructional stresses are less simple than those just described. Fortunately they are largely under the engineer's control.

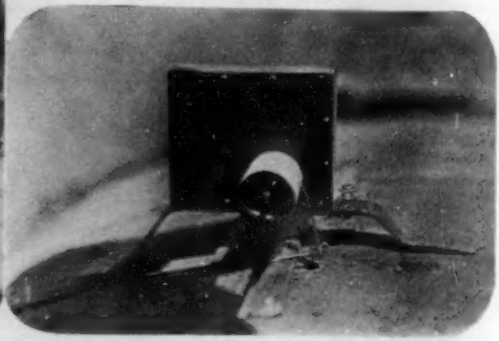
Residual welding stress

By residual welding stress I mean that stress which results from the progressive deformation of the metal as welding proceeds. In the construction of a pipe line of so large diameter as that of the Mokelumne it is imperative that each of the thirty foot sections (weighing five tons) shall lie in its final position during the time of welding. All the girth welds are thus bell-hole welds. The large diameter and weight of the pipe and the fact that twenty or more must be welded simultaneously rob the welder of the possibility of so placing the section that it can move as welding progresses. If the pipe sections are laid in their proper positions

and the welding produces a uniform tension at all points of the girth weld this will produce a uniform pull to move the pipe along the ditch and no harm will result. If the shrinkage of the weld is such as to endeavor to draw the pipe out of its axial position the resulting tension may be so large as to be dangerous. Welding deformations were measured at every foot of the circumference at a number of girth welds. Fig. 10 shows the deformation at one particular girth weld. It is here shown as measured at the time the weld was partially complete. The welded portion is indicated by the heavy outline. The deformation is exceedingly uniform. It was an excellent weld. The general procedure was

Fig. 8 (left). Stress was determined by measuring relative motion of the pipe and the free end of bar placed on the pipe.

Fig. 9 (below). The stress recorder



for two welders to simultaneously weld top and bottom and then to simultaneously weld up the two sides.

In contrast with this weld without serious residual stress Fig 11* depicts the deformation resulting from the rewelding of the upper half of a girth weld that had broken, the lower half remained intact throughout. For several feet the deformation is nearly a half inch. Such a deformation is serious. It is also avoidable.

Shearing stress

Shearing stress is introduced when the two pipe sections are not quite round and the keys and wedges force the two sheets into temporary alinement for welding. The pipe sections are thus elastically deformed. It would be far better to permanently deform the two sheets to bring them into permanent alinement for welding. One break was observed in which the two sheets moved out of parallel by 0.4 inch. This meant a large shearing stress in the weld before the break. Its value cannot be calculated. This shearing stress is particularly dangerous if failure be by the maximum shear theory as set forth by Becker.

*The words electric arc welded refer to the electric arc weld used to back up the acetylene weld.

Gravitational stress

By gravitational stress is meant that stress which is introduced by the fact that a pipe line is inclined to the horizontal. May I state without going into details of the calculation that if this 65 inch pipe line be laid on a 30 deg. incline there will result, because

Welding Deformation in Acetylene weld 659 when partially completed. Direction of welding shown by arrows. Deformation accurate to .005"

Fig. 10. Residual welding deformation at a weld; exceedingly uniform; excellent weld.

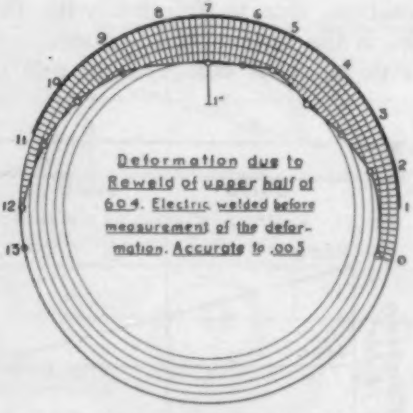


Fig. 11. Deformation due to rewelding the upper half of a girth weld that had failed

of the incline, an additional stress of 1000 lb./in.^{2}. This stress will be a compression if the line be laid uphill but a tension if it be laid downhill. Riveted pipe may fail under either tension or

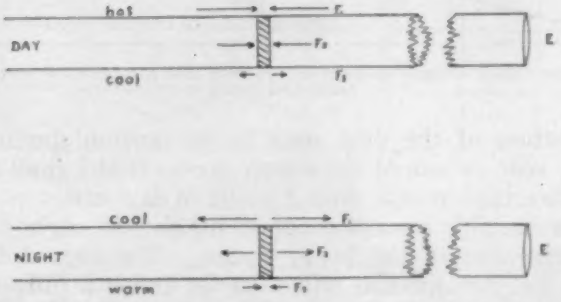


Fig. 12. The forces acting on a segment of the pipe. Daytime stresses are compressive. Breaks occur at night

compression. Butt-welded pipe will not fail under compression and therefore should always be laid uphill.

Differential-temperature stress

Differential-temperature stress is that stress introduced by joining pipe sections together at a time when the top of the pipe is warmer than the bottom. You will remember from the temperature chart previously shown that the top of the pipe is 45 degrees

warmer than the bottom from 11 a. m. to 4 p. m. every day. This corresponds to a stress of 9000 lb./in.^{2}.

Suppose a long line of pipe to be laid and joined at a time when the top and bottom temperatures are equal. During the daytime the top will be the warmer and the forces acting on a small segment of pipe will be as shown in Fig. 12. The force resisting its motion, due to friction with the ground, is represented by F_2. F_1 is the differential-temperature stress. During the daytime the pipe is under compression due to both F_1 and F_2. It is possible

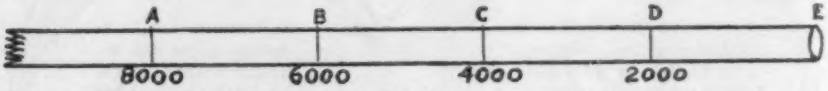


Fig. 13. Maximum stresses at ten section intervals from the free end of the pipe

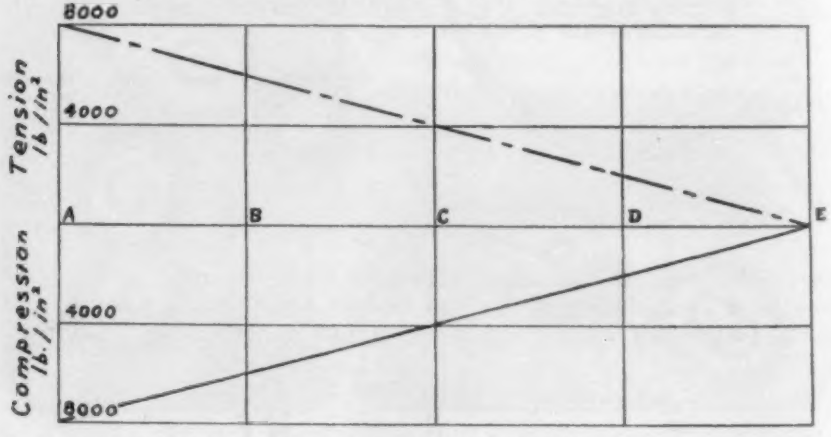


Fig. 14. The line stress alternates between tension and compression as the pipe moves back and forth

that the bottom of the pipe may be in tension during the day. This will be seen on one of the stress curves that I shall show later. It is clear then that breaks cannot occur in daytime.

Breaks in the pipe always occur at night. At night the stresses are as represented in the lower figure. The top of the pipe is cooler than the bottom and will thus be under a differential-temperature tension F_1. To this will be added the line tension F_2, the tension required to pull the pipe along the ditch. In each case F_2 is uniformly distributed, circumferencially.

The temperature curves showed that by 9 p. m. the top of the pipe is almost as much cooler than the bottom as it is to be at any time during the night. It is quite obvious then that breaks should occur during the early part of the night and indeed that is exactly what happened.

Differential-temperature stress cannot be relieved by axial motion of the pipe. For that reason expansion joints cannot relieve this stress.

Line stress

The effect of motion of a pipe line on residual tension is readily seen from the following consideration. Suppose there is no differential-temperature. Suppose that pipe is being laid at the rate of twenty sections per day, each section being 30 feet long, and that

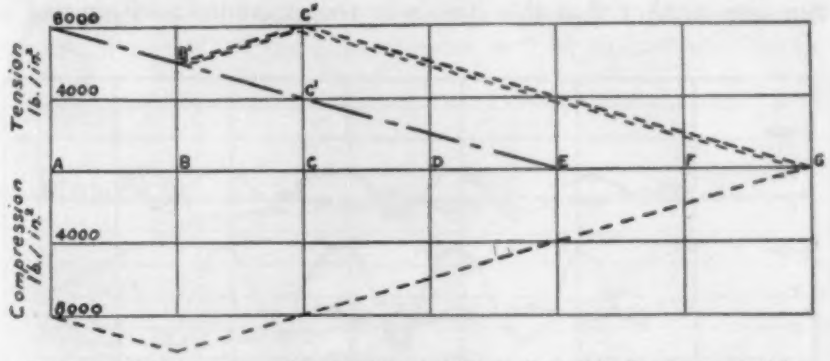


Fig. 15. When twenty sections are joined at E at daybreak, the group B' C' is permantly elongated

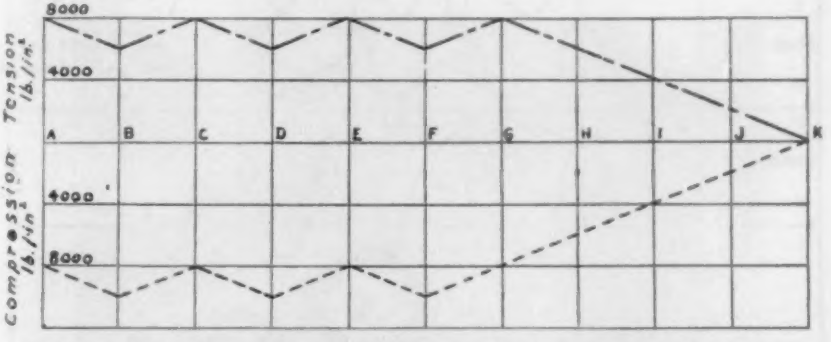


Fig. 16. The line stresses resulting from joining twenty sections daily

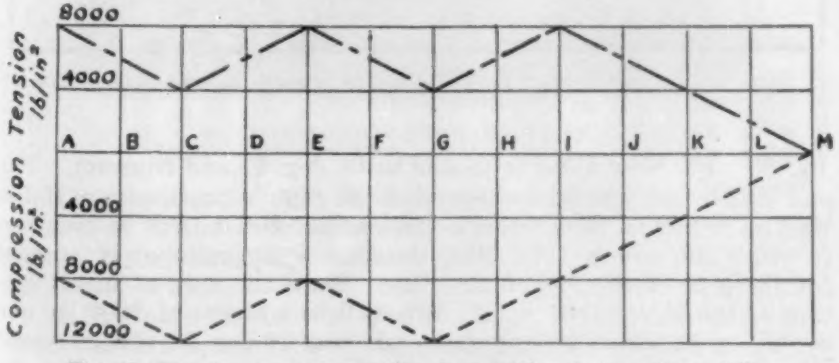


Fig. 17. The line stresses resulting from joining forty sections daily

their central portions are immediately covered with dirt which forms a friction load of 20,000 pounds for each section. Assume that no pipe is laid during the time the temperature is changing but only while the whole line is at the lowest daily temperature.

Let each of the divisions AB, BC, etc., Fig. 13, represent a group of ten sections of pipe, each group being 300 feet long. Suppose further that this line is in the expanded position and at

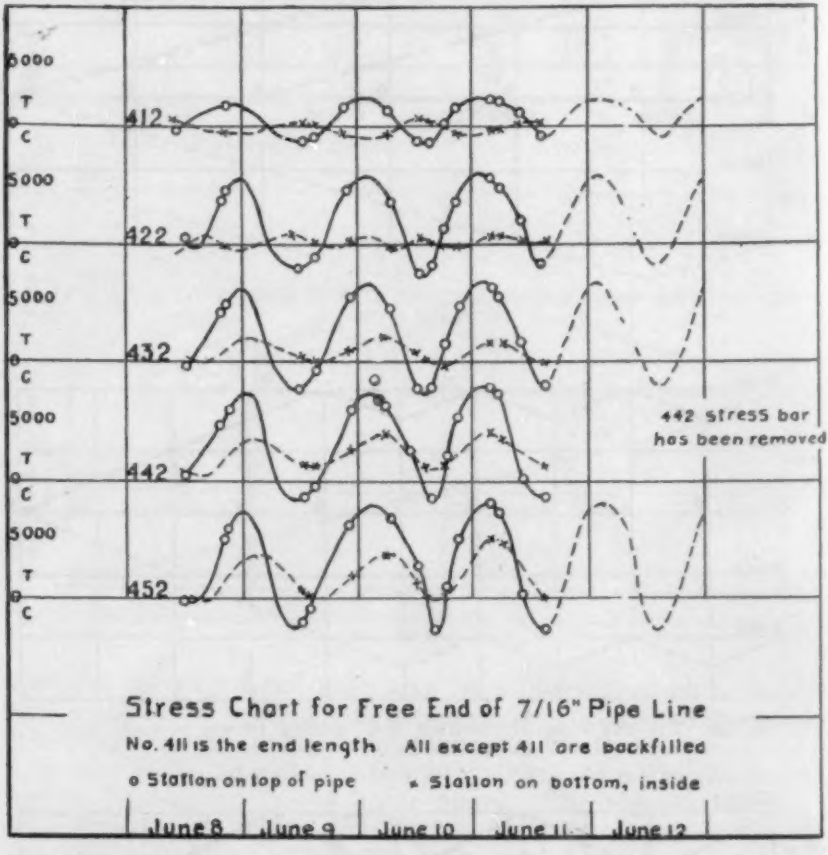


Fig. 18. Stress records for the top and the bottom of the pipe at ten section intervals from the free end

100 deg. F. Now allow it to cool to 60 deg. F. and contract. The end E is a free end while beyond A the pipe is continuous. If the load be 20,000 lb. per section a force of 200,000 lb. will be required to move the group DE. This loading is approximately correct for the pipe of the Mokelumne line. Since the area of metal section of the pipe is 100 sq. in., this will be a stress of 2000 lb. per sq. in., equivalent to a temperature drop of 10 deg. F. The stresses at points A, B, C, etc., will be as indicated numerically in Fig. 13

and by the broken line in Fig. 14. They are tensions when the pipe is contracted.

The temperatures 140 deg. F. and 60 deg. F. are used as maximum and minimum temperatures in this discussion. They are actual values for June, 1926.

If during the following day the temperature increases to 140 deg. F., a rise of 80 deg., the stresses will be as indicated by the

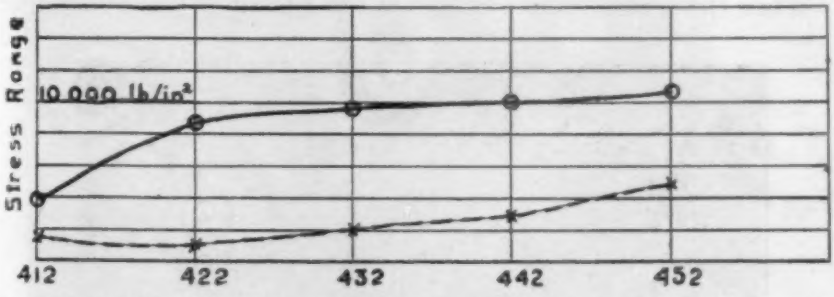


Fig. 19. Maximum stresses at top and bottom. 600 ft. from the end, the top stress is almost as great as anywhere in the line

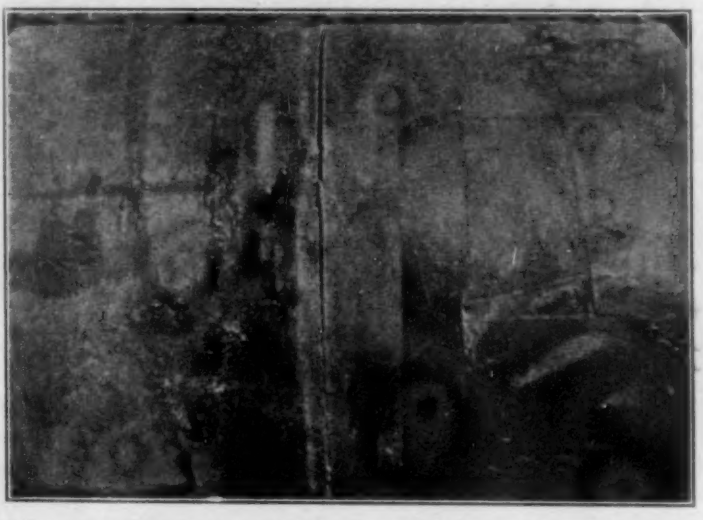


Fig. 20. A bad fracture. Only differential temperature stresses and residual welding stresses were relieved by this break

solid line in Fig. 14. The 80 deg. rise was sufficient to remove the tension at A and to introduce a compression of 8000 pounds per square inch. Since this is barely sufficient to cause motion, A is an anchor point.

At B, where the tension was 6000 lb. per sq. in., a rise of 30 deg. was necessary to remove tension. The remaining 50 deg. introduced a compression of 6000 lb. per sq. in. and caused movement.

Suppose that during the night when the temperature is lowest and constant for a long time an additional twenty sections of pipe are laid and joined. The stress diagram will then be as shown in Fig. 15. The broken line indicates the tension at the time of joining the pipe. The dotted line indicates the compression at the time of highest temperature and the double dotted line shows the values of the tension at the close of the day when the temperature has again returned to its lowest value.

When the compression was greatest the point B was an anchor

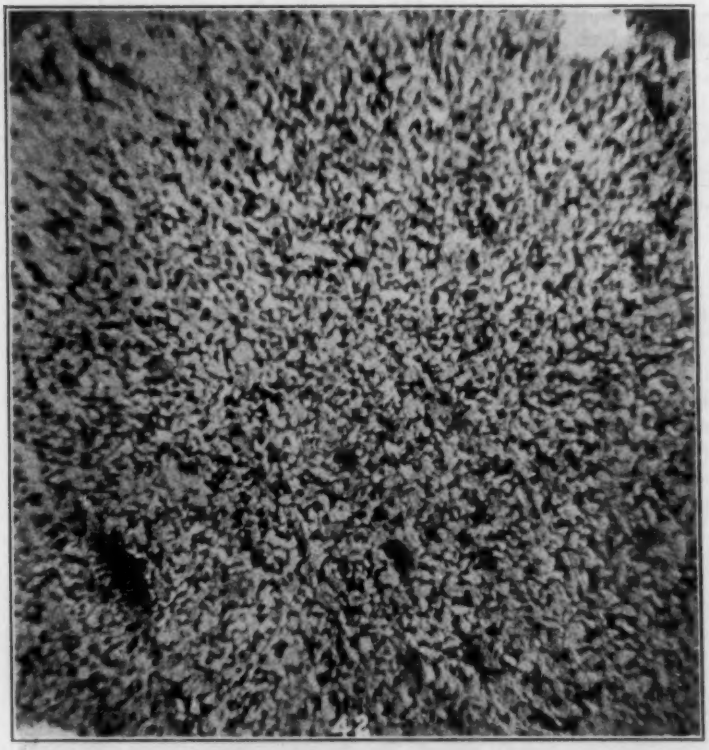


Fig. 21. The structure of the steel of the pipe, 0.15 carbon. X100.

point and all points to the right of B moved outward. As the temperature dropped to its lowest value the tension indicated by the double dotted line shows that C was an anchor point and only points to the right of C could have a motion of recession. The portion to the right of C is now identical with Fig. 14. This has resulted in a permanent outward motion of C, a permanent increase of tension as indicated by the displacement of the dashed line B′ C′ to the position of the double dotted line B′ C″.

If, during a number of succeeding nights, twenty sections are laid and joined each night at the time the temperature is lowest,

the maximum stresses, compression and tension, will be as indicated in Fig. 16.

If forty sections are joined to the line each night while the temperature is lowest the resulting line stress will have maxima as shown in Fig. 17. Comparison of Figs. 16 and 17 shows that

Fig. 22. The center of the acetylene weld. Iron, large crystal structure. 100X

laying and joining a large number of sections each night enables one to leave the line in less tension.

The larger the number of pipes laid each day, the lower is the average tension left in the line at the lowest point of the temperature range. On account of the viscous nature of the resistance of the pipe to motion, the tension at all points will come to this average.

Laying and joining a single section daily would leave the line stress equally divided between tension and compression, half the stress range being the maximum value of each.

If in Fig. 17 the words compression and tension are interchanged the stresses indicated will be those that would result from the laying and joining of forty lengths daily at the time of highest temperature. The advisability of joining at night is easily seen.

I shall not bore you with an extended description of our measure-

ments of line stress. Suffice it to say that during a normal summer day 40 semi-backfilled pipe sections, 1200 ft., move outward along the ditch and return at night. To move these 40 sections requires a force of 840,000 lb., a maximum of 8400 lb./in.^{2}.

It will be interesting to show you here the measured values of the stresses obtained in a systematic study of the stresses of the 65 in. x 7/16 in. pipe. In Fig. 18 pipe section 411 was the free end of the line and 412, at which stresses were as shown in the

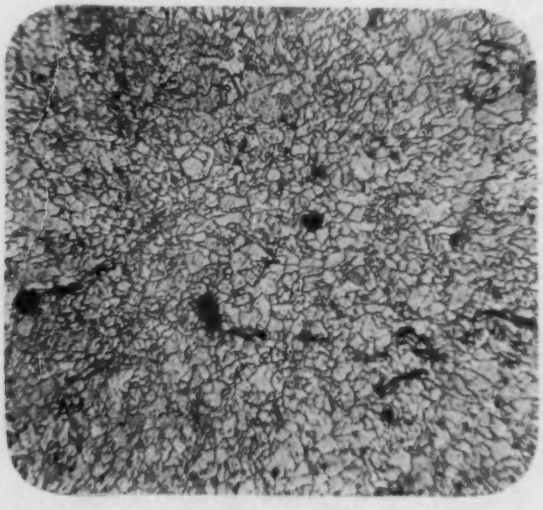


Fig. 23. The acetylene weld normalized by merely heating and allowing to cool. X100

upper pair of curves, was the second weld from the end of the line. The solid curve represents the stress at the top of the pipe and the dotted line that at the bottom of the same section. You will notice that the top and bottom stresses are exactly out of phase. That is to be expected near a free end.

Weld 422, with stresses as shown in the second pair of curves, was ten sections or 300 ft. from weld 412. Peculiarly enough the bottom stress at this point is almost zero.

Passing on to the last pair of curves, the stresses at 452, we see that top and bottom stress are almost in phase but not quite equal in magnitude. It may be interesting to you to know that the paucity of points on these curves is due to the fact that each pair of points necessitated 4 miles travel with a half mile walk inside the pipe. That was one reason why it was necessary to devise a recording stress meter.

Both top and bottom stress increase as we go away from the free end. In Fig. 19 the solid curve represents the top stress as a function of the distance from the free end. The dotted curve is for the bottom stress. It is seen here that the top stress at 10

I shall not bore you with an extended description of our measure-

sections (300 feet) from the free end is almost as large as at any point of the line. The bottom stress is least at this point. This pair of curves is the reason underlying our method of group laying for large pipe. Group laying has been used for years in the laying

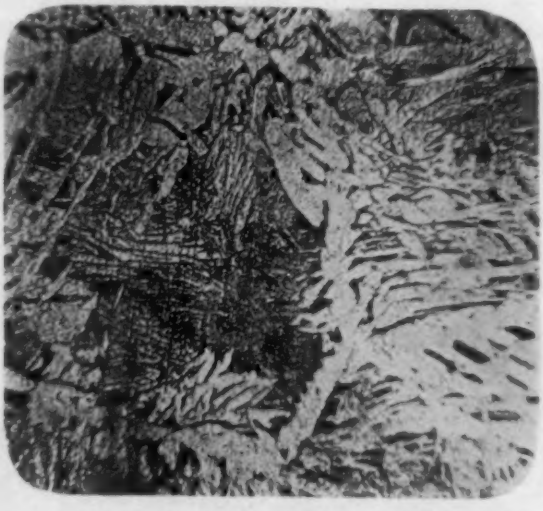


Fig. 24. Large crystal structure at the junction of the added metal and plate. X100

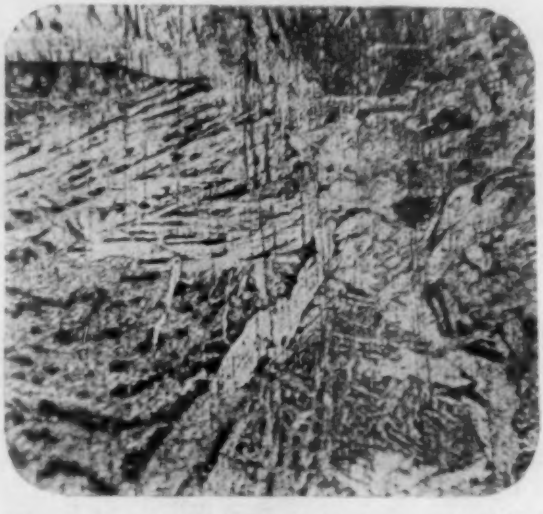


Fig. 25. Large crystal structure in a normalized vanadium steel weld. X100

of smaller pipe but not for reasons in connection with stresses. This pair of curves also shows clearly that if expansion joints were to be provided for the relief of stress it would be necessary to place them certainly no more than 40 sections, 1200 ft., apart. Expan-

sion joints are, however, entirely unnecessary; at least so in any water pipe laid underground.

Now let us add up the values of the maximum longitudinal stresses that we have tabulated. The stress marked * is not generally present and is therefore omitted. The total, 17,250 lb./in.^{2}, does not include line stress for the reason that it is partly caused

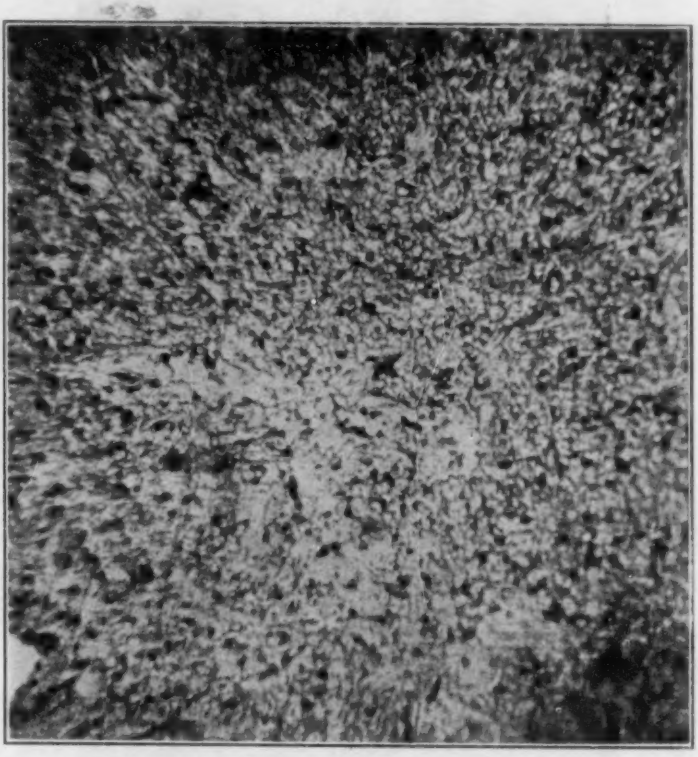


Fig. 26. The satisfactory structure of a normalized vanadium steel weld. 0.10 per cent carbon. X100

by differential-temperature stress. The two are not independent and cannot be merely added to obtain the total.

Cold-water stress cannot be reduced.

Poisson stress is inherent.

Differential-temperature stress may be entirely eliminated by choosing the proper time for welding.

Line stress may be reduced to 4500 lb./in.^{2} by laying the sections in groups and then joining the groups, due care being exercised to choose the most suitable time for joining the groups. (I shall not discuss the stresses involved in group laying unless you should particularly desire it). This leaves but 12,750 lb./in.^{2}, which the line should be able to withstand.

Fig. 20 is a photograph of a typical break that occurred. Of

sixty eight breaks that occurred only two were breaks of the entire weld. Remember that without a break of the entire weld no line stress could be relieved. The only stresses that *were* relieved were differential-temperature stress and residual welding stress. If we admit that residual welding stress is the same in the bottom of the pipe as at the top then we must also admit that in sixty-six of the sixty-eight breaks that occurred it was differential-temperature stress that did the trick. And how easy it would have been to eliminate it!

You will notice in this photograph that the fracture is right down the center of the added material. I shall endeavor to convince you that both constitution and structure of this metal were at fault.

Fig. 21 is a photomicrograph of the metal of the pipe, 0.15 per cent carbon and of excellent crystalline structure. Fig. 22 is the added material, at the center of the acetylene weld. Notice the

BREAKAGE IN ACETYLENE WELDS

Welds	Total breakage ft.	Number of breaks	Average break ft.	Remarks
1 - 99	96.9	12	8.1	1 D.P.*
100 - 199	169.3	23	7.36	3 D.P. attempt to get into production
200 - 299	17.5	4	4.4	7 D.P. 1 bend
300 - 379	5.0	2	2.5	79 welds in group
411 - 499	13.0	4	3.25	90 welds in group 1 D.P.
500 - 599	15.8	6	2.64	1 bend
600 - 699	54.7	15	3.65	Attempt to crowd welders for footage.
700 - 799	8.1	5	1.62	2 D.P. 1 Bend, vertical
800 - 854	3.5	1	3.5	54 Joints in group
Totals	366.8	68	5.39	823 welds

* Distance Piece

2.54 % of total acetylene welded footage broke.
Average break 30.8% of full weld.
14402 linear ft. of weld.
4.54% rivets removed on first 371 riveted joints.
4.44% of weld broke on first 371 joints.

Fig. 27. A statistical study of the breaks of the acetylene welds

large crystal structure and the entire absence of carbon. The magnifications are equal, 100 diameters. Analysis showed 0.03 per cent carbon. Fig. 23 shows this metal normalized by merely heating with the torch and allowing to cool. The metal is now ductile. Fig. 24 shows the exceedingly large crystal structure that was left just at the junction of the added metal and the parent metal. Figs. 25 and 26 show a weld that was made with a low-carbon vanadium rod. It is shown before (Fig. 25) and after being normalized by the torch. Notice how the coarse brittle structure is changed to a structure that is satisfactory and that a fair amount of carbon is present, 0.10 per cent. These normalized welds were not brittle, as hammer bending tests showed.

Before drawing our conclusions I should like to return for just

a moment to some of the interesting statistics obtained. Fig. 27 tabulates the number of breaks and the average linear feet of break, in groups of one hundred welds. You will note that the breaks decreased in both number and length as the work progressed, the only setback occurring when an attempt was made to hurry the welders.

It is psychologically interesting to note that in the first 371 riveted joints that succeeded the welding it was necessary to remove 4.54 per cent of the riveted footage whereas only 4.44 per cent of welding had failed in the first 371 joints. No one has suggested that this is a serious fault in riveting nor apparently given it serious thought.

Now you know and I know there is no inherent reason why welding should not have been perfectly satisfactory in the construction of the Mokelumne Pipe Line. In conclusion then I shall point out the ways in which it might have been changed to make it satisfactory.

(1) By welding at night to avoid differential-temperature stress but two breaks would have occurred. There is a great possibility that even these would not have happened and that the whole project *might* have been considered satisfactory in spite of the large crystal structure and low-carbon content of the metal of the welds. The welds would then have had to withstand but 16,650 lb./in.^{2} in addition to any residual welding stress that may have remained.

(2) By welding at night and normalizing the metal of the weld it is *very probable* that not a single break would have occurred.

(3) By welding at night, changing to a low-carbon vanadium rod or a similar suitable rod and normalizing the metal of the weld the welds would have been 10,000 lb./in.^{2} stronger than anything they would be called upon to stand.

(4) If in addition to this the pipe had been properly laid in groups of twenty and the groups joined together the welds would have had 14,000 lb./in.^{2} excess strength and I cannot imagine how they could have failed.

All this supposes there to be no internal electric arc weld, and further supposes the work of the welders themselves to be in no way superior to that actually performed.

I have given you a rather brief summary of the purpose and results of our investigation. There were many interesting little experimental diversions and some attendant interesting results that we shall not have opportunity to discuss.

In justice to Professor Weeks with whom this study was carried out, and to myself, I should state that our investigation was begun just at the time the change to riveting was ordered.

I should also mention the fact that one and one half miles of the line have now been electric arc welded, adopting in its entirety our program for group laying and our method of avoiding differential-temperature stress and that during this construction the breakage has been zero.

Before drawing our conclusions I should like to return for just

Discussion of Paper on "The Welding of the Mokelumne Pipe Line" by Professors L. T. Jones and W. S. Weeks

Chairman F. E. Rogers, Air Reduction Sales Co.: This is a joint meeting of the two societies, American Society of Mechanical Engineers and the American Welding Society. The discussion is open, of course, to members of both societies and others who are not members of either society, provided they have something pertinent to offer in this matter.

I think we are greatly indebted to Professor Jones for his masterly exposition of the stresses set up in pipe lines under abnormal conditions; conditions that have never before been experienced in laying welded lines.

Mr. Miller, will you open the discussion?

Mr. S. W. Miller, Union Carbide & Carbon Research Laboratories: Mr. Chairman and Gentlemen: I want to personally thank Professor Jones for what he has done and said. I think that our congratulations ought to be extended to him for the work that he has done, work that has never been done before, and that we ought to extend our felicitations to him for stating so very clearly what he has stated. I have had the pleasure of talking over some of these things with Professor Jones and I am glad to say that I don't agree with him altogether. I don't think that it is right for us to agree on many of these things. I do want to say that I agree with him thoroughly on his analysis of the stresses and his description of the means by which they can be avoided. I am entirely in accord with that.

There are one or two things I would like to speak about. Professor Jones has referred to vanadium steel as a welding material. A good many years ago a large steel company got out what they called a type F steel welding rod. It contained about .06 per cent carbon and .15 per cent vanadium. That was called a vanadium steel welding rod, but that is not the type of welding rod that Professor Jones refers to, as that material was bad welding material. It makes exceedingly brittle welds, so much so that if a test piece half inch by two inches is clamped on an anvil and struck one blow with a ten-pound sledge it will break off short. I think this is a good reason for that not being a satisfactory rod. If I am not in error, the welding rod that Professor Jones refers to was a very widely different composition, and in accordance with well-known metallurgical principles it should be a very good welding rod.

I am also somewhat in disagreement with Professor Jones on his statement that normalizing welding material of that kind increases its tensile strength 10,000 lb. to the sq. in. I think he has taken his figures from some of the formulas which have been so widely published, based on the strength of forged material, but which, I

has been zero.

think, are not applicable to welds. I know that it is my experience that normalizing will not increase the strength of a weld 10,000 lb. per sq. in., though it will somewhat increase the ductility. But here again, another point enters. On forged material the effect of normalizing is very marked, and in alloy steels, in which the vanadium steel welding rod may be classed because it has more than the usual amount of manganese and silicon in it, there is a marked effect from heat treatment. In the weld, however, there are so many other things that have an effect that normalizing does not cause an increase in the strength of the weld.

You must consider that there may be defects in the weld. They may not be serious, and they may be. But it has been my experience that you must consider in all cases the quality of the weld; that is, its freedom from laps and inclusions, its quality of fusion and its penetration at the bottom of the "V." Those things all have a far greater effect on the strength of the welded joint than does any normalizing.

As an illustration of what I mean, let us suppose that we have a single "V" weld which was the type of welds that were made on the Mokelumne line. It is usual practice to reinforce such welds a certain amount, and it is also 99 times out of 100 the fact that you do not get full penetration to the bottom of the "V." Let us carry that to the limit. Supposing that we butt two pieces of pipe together and weld across so that the weld deposit forms a ring around the pipe, making the section of that weld sufficient to stand the theoretical stress on the pipe, or make it, if you will, equal in strength to the pipe. Also make the shearing stress along this surface equal to the tensile strength of the pipe. Now, it has been our experience from actual tests, both in tension and bending on full size pipe—not sixty-five inches in diameter, but up to fifteen or sixteen inches in diameter—that the rupture either in tension or bending always occurs there, and the reason for it is that you do not have a uniform stress distribution across the joint. It is uniform up to here, but it gradually concentrates because there is no resistance at this point to transmit the stress. This "V" weld, not welded at the bottom and reinforced at the top, differs only in degree from that. The stresses concentrate here. (Illustration.) And the result is that you have on there the combined bending and tensile strength which, as Professor Jones has pointed out, very much increases the fiber stress at the joint.

I have no information as to the quality of the welds made, but I feel quite sure that that is the type of welds they make. The natural result is the fiber stress is so great it breaks through there. I would point out in particular that none of the welds that were welded entirely through broke. And I might also say that I have never known a double "V" type weld to break. I want to emphasize that I have never known, nor has anybody ever been able to bring to my attention, a case of a double "V" type weld breaking in

service. I might say further that all of our high pressure tanks, of which we have built a great many, and which are tested to three times the working strength, have never given any evidence of failure, or even distress, at any of the welds and they are all double "V" welds. We believe that is the only safe construction.

The internal evidence, to me, in this whole matter is that, had the welds been made of the double "V" type, there never would have been a weld break on the line. Even low carbon steel would have been good enough, because that material has a tensile strength in the weld, when it is the same section as the plate, of about 50,000 lb. per sq. in.

Professor L. T. Jones: Our problem was not to show whether a weld can be made to be satisfactory. Our problem was to show this: Take off the internal electric weld, deposit a better metal without changing the extent of the deposit, eliminate stresses as should have been done, and then they would not have failed.

I agree exactly with what Mr. Miller says, that a weld on the other side (double V) would have strengthened it quite a lot and not a single one would have broken.

We are apparently not discussing the same thing. You will find in the manuscript I did not ascribe 10,000 lb. per sq. in. to normalizing the vanadium steel weld metal. That referred merely to ten points carbon that remained in the vanadium steel weld; and we will suppose ten points carbon means 10,000 lb. per sq. in. added tensile strength, to say nothing of the effect of the vanadium, manganese, silicon. So this 10,000 lb. is not ascribed to normalizing. What effect normalizing has, I do not know. I am not able to prove that it in any way increases the tensile strength. I can't prove that it does not.

Mr. J. W. Owens, Newport News Shipbuilding & Dry Dock Co.: I desire to reinforce what Mr. Miller has said in appreciation of Professor Jones' able analysis of the various stresses encountered in pipe line construction. This analysis not only increases our engineering knowledge, but assists in answering the inevitable "Why?"

As many of you know, the Newport News Shipbuilding & Dry Dock Co., with which I am associated, is furnishing all the steel for this line, the plates being planed, ends bevel sheared to length, and shipped flat, by water, to the West Coast through the Panama Canal. Welding was used on this line because it made possible a decrease of over 30 per cent* of the total price for a completely riveted line. The original specifications for a completely riveted pipe line called for pipe having a maximum inside diameter of 68 in. and material up to 9/16 in. and ⅝ in. in thickness. As a welded line, the maximum thickness of material required was ½ in. and the corresponding inside diameter was 65 in.

While our company has not the contract for welding, nevertheless it is keenly interested in its successful application, due to the

*See article by Mr. Arthur P. Davis, Chief Engineer, East Bay Municipal Utility District—*Engineering News Record,* December 2, 1926.

large financial investment involved; therefore, as a result of repeated failure of the gas welded circumferential field joints, I went out to the Coast with some of our executives to see what could be done. Before arriving there, however, the district's engineers had ordered the gas welding of the circumferential field joints to be

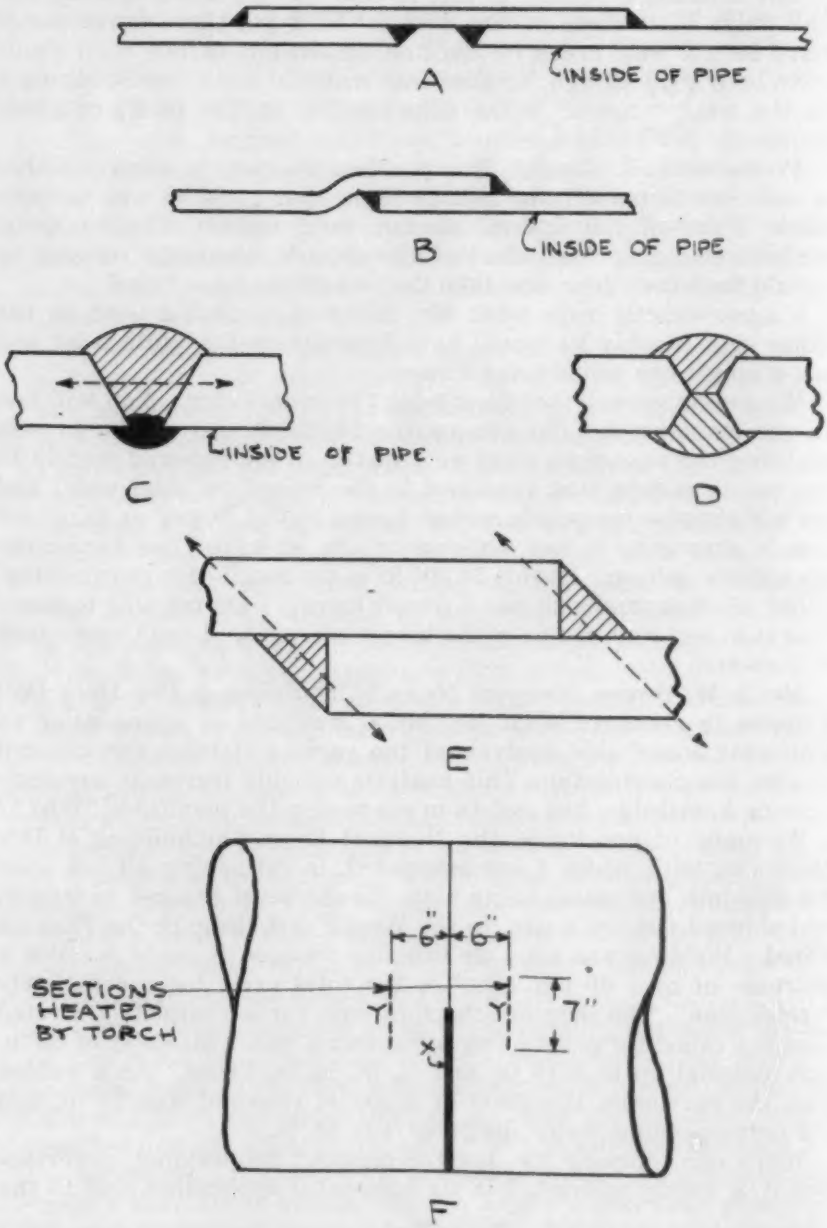


Fig. 1

discontinued, specifying that a riveted strap joint should be used.

The problem in all its phases was discussed with the district's engineers, the welding contractors, the men in the field, and Prof. Jones. I found that, due to repeated failures, the district's engineers would not consider any further use of gas welding. That being the case, I felt that something should be done to demonstrate that at least one welding process could be satisfactorily employed, and I suggested to Mr. Davis that metal arc welding be considered for a section of the uncompleted portion of the line and that the double lap joint, Fig. 1-A, or joggle lap joint, Fig. 1-B, be used.

As a result of this, approximately 1.3 miles of pipe were subsequently welded by the metal arc, using the double lap joint, Fig. 1-A, and low carbon steel electrodes. In this connection, not only has Prof. Jones stated this evening that no failures occurred in this section, but Mr. Davis confirms it in the *Engineering News Record* of Dec. 2, 1926, in the statement that "very good results" were obtained. Again, it is understood that another mile of pipe has also been successfully welded by the metal arc, using the joggle lap joint, Fig. 1-B. This joint has the advantage over the double lap joint in that only half the amount of weld metal is necessary per joint and both joints (Figs. 1-A and 1-B) have advantages over the butt joints (Figs. 1-C and 1-D) in that they are easy to assemble in the field, permit adjustment of the sections necessary to take care of changes in length caused by differences in temperature, and that, should failure occur in the weld under operating conditions, there would be a minimum loss of water, due to its having to find its way through the lap of the joint.

I do not agree with Prof. Jones' conclusion that residual welding stresses are of minor importance compared to some of the other stresses classified by him, and that weld failure would not have occurred if the procedure outlined by him was followed. If the successful welding of buildings and other structures depends on a greater knowledge of the various stresses encountered than has been found necessary over years of riveting practice, then welding development will be seriously handicapped; however, the fact that two miles of this pipe line have been successfully welded by the use of the lap joint and by the metal arc should indicate that this is at least one practical solution of the problem.

Lap joints have a lower residual stress than butt joints for the reason that cooling stresses are transverse to the joint, as shown in Fig. 1-E, whereas in the butt joint, Fig. 1-C, they are in the same plane as the joint. The only way that a "fixed" butt joint (the type used for the circumferential joints) can be successfully welded by either the arc or gas welding processes is to properly reinforce it, preferably on both sides, so as to take care of residual and the other stresses enumerated by Prof. Jones.

It is not only probable, as suggested by Mr. Miller, that the weld metal in the gas welded single V joints which failed did not

penetrate to the bottom of the single V, but this was actually the case, and was one of the causes of failure. This conclusion is verified by Mr. Davis in the article previously referred to, wherein he states that "oxy-acetylene welds that have been backed up by electric welds are not subject to cracks" and that "in a few cases where electric welding was not, for some reason, carried entirely around the circumference, the external weld cracked for that portion of its length on which the electric weld was lacking." Another reason of failure of the gas welded circumferential joints is that the field technic developed on the job, as the result of practical experience, was not consistently adhered to. For example, I saw a three-inch crack at the end of a circumferential weld "X," Fig. 1-F, due, it was claimed, to the fact that parallel sections "Y" were not heated by another torch when the operator ceased welding.

Professor Jones has stated that it is essential that vanadium steel filler metal be used for successful welding, so as to retain the carbon in the weld. I have not found this to be the case, and however desirable it may be to obtain a greater unit strength of weld metal by the retention of carbon, nevertheless the fact that the first mile and possibly the second mile of the metal arc welded circumferential pipe line joints were welded with low carbon steel electrodes and that failure of the gas welded butt joints, made with low carbon steel welding rods, was overcome by reinforcement of the weld on the inside of the pipe, would indicate that gas and metal arc circumferentially welded joints can be successfully made with low carbon steel filler metal, provided the total weld section in the joint has a greater strength than the base metal.

Mr. Miller states his preference for the double "V" butt weld, Fig. 1-D; unfortunately, however, in my opinion, it cannot be used for gas welded pipe lines because of the difficulties encountered in securing adequate ventilation to dissipate the heat and gases. It was, for this reason, that the single "V" gas weld was reinforced by a metal arc deposit instead of a gas deposit. Again, my experience has shown that equally satisfactory single "V" butt welds can be obtained by proper reinforcement on both sides of the joint.

Although Prof. Jones has stated that his recommendations for laying the pipe line were followed in the first mile of metal arc welded pipe, nevertheless, in my opinion, lap joints, Figs. 1-A and 1-B, can be successfully welded with the metal arc, with low carbon steel electrodes, at any time of the day, and in any sequence of weld deposition.

Professor L. T. Jones: This particular procedure (sketching) was followed only toward the close of welding. I did not agree with certain things that were done. I did not take any part in determining the procedure that was to be followed in making the weld. I think that is not the serious matter.

As regards ventilation and the possibility of making an internal

weld; you, Mr. Owens, should have been in that pipe when the arcs were going.

Now, I don't mean that to be a disparaging remark about arc welding. Ventilation is necessary, whether in arc welding or gas welding. I agree with you in the possibility of doing either inside. At one time inside that pipe we measured air velocity and found 500 cu. ft. per minute going through the pipe, and the temperature in the middle of the pipe was 100 deg. fahr. The temperature up at the top was 140 deg. Resetting the blower produced an air movement of 11,500 cu. ft. per minute—from the same blower!

It is perfectly possible to weld that pipe line by a gas weld or by the electric arc, and I don't care which you use. But I do believe in the desirability of eliminating unnecessary stresses. I also have pointed out in a completed study, now being published, that we know the gas welding could have been carried on all twenty-four hours in the day, although actually eight hours only were utilized and twelve hours were available during which differential temperature was negligible.

Mr. Brush: I would like to ask Professor Jones to what extent the transmission joints were tested as to tensile strength, as to utility bending test, and what percentage of strength was developed in the circumferential joints.

Professor L. T. Jones: The district engineer was given the privilege of cutting a coupon from any joint he chose at any time. If he found it to be faulty he could cut another within six inches, and if the second was found faulty that was to be sufficient reason to discharge the welder. They did not exercise that right. The welders were competent. A number of coupons were cut from the field joints, I believe about forty, of which I have record. I do not have the record with me, nor is it important, because of the fact the coupons were usually cut from the weld in an endeavor to pick out the weak spot, which the district engineer knew and kept in mind. That was the reason he did it. He wanted to find the weak spots. So for that reason listing of those tests would not be of value any more than it would be of value for me to list all the rivets that have failed, and to list none others except the ones that failed. So that information is not as extensive as you may wish, and I don't believe such information can be presented to be of any value. Tensile strengths of the coupons cut ran all the way from about 17,000 to the strength of the plate, which means nothing, because you might have 17,000 any time if you happen to pick a two-inch place where penetration was not good. Yet the average of those taken out was decidedly more than the 17,000 total stress I have mentioned for the pipe!

Immediately you take out the coupon you are eliminating some of the stresses that were present. You certainly eliminate shear stress, and shear stress, in one weld, I think, actually caused the failure, or was the determining factor. When you cut out a coupon

it is not the same after you cut it out as before. In that one particular feature, I think, those tests are sometimes mistaken.

Mr. Brush: Were any bending tests made of those coupons?

Professor L. T. Jones: I am not aware of any case in which it was made. The actual field coupons were tested only by tensile tests. To demonstrate fitness for employment, prospective welders each welded a coupon which was given a 120 deg. bending test.

Mr. Brush: I would like to add my personal appreciation of the analysis Professor Jones made of the stress in the pipe due to various causes. I certainly agree most heartily with him in his conclusions that, as engineers, we ought to eliminate as far as possible these preventable stresses. We are trying to get a pipe line that will be subjected to stresses that we cannot predetermine, and with our construction here in the city we have stresses developed in our circumferential joints due to changes in our foundation settlements where it would be of great value if we can develop satisfactorily a joint that comes very close to 100 per cent of the strength of the pipe—our present joint of a riveted design is probably around 54 per cent, and that is where our pipe lines are going to give way. We have not given any special attention to the question of riveting at a time of day when it would minimize the stress that would ultimately develop in those joints. Here our problem is not nearly as serious as where you have a forty degree temperature difference in the pipe. But it is a great aid to have presented so clearly and so satisfactorily as Professor Jones has presented, the stresses which could be prevented in joining up the steel pipe sections.

Professor L. T. Jones: The temperature of 140 deg., incidentally, is not the highest. I have seen it 160 deg. The region over which the pipe line has thus far progressed is not the hot part of the valley. During the next month or two months I think it will be a common thing to have a temperature on top of 160 deg. and possibly higher. There is one other interesting feature. That is on the riveting, and this is a virtue that the riveted joint has over the welded. On the riveted pipe, we measured ten successive riveted joints and all ten were slipping. When it slips it relieves stress, and that is the virtue the riveted joint has that the welded joint does not have. When it slips it leaks. That is too bad, but nevertheless it reduces stress.

Mr. E. A. Doyle, Linde Air Products Co.: I would like to ask why they used the electric arc instead of gas when they changed to different types of joints, the one where the strap was put around, and the one where the end of one was expanded and inserted the end of the other. Was it for the purpose of economy, or was it an easier method of application, or what was it?

Mr. J. W. Owens, Newport News Shipbuilding & Dry Dock Co.: I think it was admitted by those who use gas welding almost exclusively that the fillet weld is a very unsatisfactory weld to make

by the gas-welding process. The butt weld is very much to be preferred for gas welding as against the fillet weld. The district engineers said they would not have any more gas welding.

They had taken that stand very positively and the only thing to do was to try to get at least some other form of welding on the line.

Mr. E. A. Doyle, Linde Air Products Co.: I think the gas welders do not admit it is impossible to make a good strong fillet weld with gas. They do say if the fillet weld must be made, you certainly can make it just as well with gas as electric arc.

Professor L. T. Jones: I think I should explain one apparent discrepancy between the viewpoint expressed by Mr. Davis in his article of Dec. 2 in *Engineering News Record* and the conclusions I have given, because there is no discrepancy in our viewpoints. I think Mr. Davis and I completely agree. Mr. Davis said the acetylene welds failed, without any concern as to what could be done to make them satisfactory. My viewpoint was, and is, that the acetylene welds as they were made failed, but here are the things you do to make them satisfactory.

Mr. S. C. Lumm, Commercial Acetylene Supply Co.: There was a disagreement with Professor Jones on the vanadium rods used. I would like to ask if Professor Jones has the analysis of the vanadium rods?

Professor L. T. Jones: The vanadium rod was not analyzed before, but the weld metal was analyzed for carbon and for vanadium. It contained 0.10 per cent carbon and 0.22 per cent vanadium. We were not interested in the other constituents, nor were we concerned with the analysis before deposition.

Mr. Denny: I would like to ask Professor Jones if the differential stresses are effective as with water in the pipe, or were they measured with the pipe empty?

Professor L. T. Jones: Measured with the pipe empty.

Mr. Denny: Would you consider there would be a difference?

Professor L. T. Jones: The differential-temperature stress is effective when the pipe comes to a uniform temperature.

Mr. C. W. Comstock: I would like to ask how the longitudinal joints were made?

Professor L. T. Jones: The longitudinal seams were made with the carbon arc process. If I remember correctly, the longitudinal seams of this particular pipe were presented before the December meeting of this section by Mr. Lincoln. That is in the "Journal of the American Welding Society," and you can read Mr. Lincoln's discussion. He can give you very much more information than I. Each pipe section was tested by closing the ends and filling with water. In the sixty-five-inch pipe the water pressure went up to 365 lb. to the sq. in. The pipe was hammered on each side of the longitudinal seams. I personally sat on top of one of those pipes undergoing pressure test and while it had 400 lb. pressure. It

grew a quarter of an inch in circumference while I sat there, then I got off.

Mr. J. W. Owens, Newport News Shipbuilding & Dry Dock Co.: The longitudinal joints were tested with a sixteen-pound sledge mechanically dropped every six inches along the seam while under pressure, so one can see what tremendous stresses that joint was subjected to. No riveted joint ever yet made could stand such stresses as that.

Mr. E. A. Doyle, Linde Air Products Co.: I want to ask if the original welding rod was used, or was welding rod made up?

Professor L. T. Jones: The original welding rod, the low carbon welding rod for girth welds. You can obtain the specifications from the American Welding Society. It is around 0.08 per cent carbon, and so on.

This is a problem, I think, for the American Bureau of Welding: We have customarily determined the effect on steel of each of a few constituents, the total forming 1 per cent of the steel. Let's find out what the other 99 per cent does. Because the difficulty with that welding rod was, I think, due to the other 99 per cent. What was in the other 99 per cent, I have no means of knowing.

Mr. C. A. McCune, American Chain Co.: I am quite sure that the welding material used on that job does not conform to the American Welding Society's specifications from sample which was submitted to me. The rods in the gas welding contained a larger percentage of copper, and where the carbon arc was used it was a wire which did not conform to the specifications.

Professor L. T. Jones: The metal in the longitudinal seams did not form a part of our work. It proved satisfactory. I do not have a copy of the analysis. I have copies, not before me at present, of the analysis of the low carbon welding rod used in the girth weld, and while I think it was a very poor rod, it did meet the specifications of the American Welding Society. I do not remember the details of it, except 0.08 per cent carbon.

Now the specifications that the chief engineer had written were based on American Welding Society's specifications, and the analysis they had made and which the contractor had made satisfied him as to chemical analysis.

Mr. C. A. McCune, American Chain Co.: I might add, the maximum carbon content of the American Welding Society specifications is 0.06.

Professor L. T. Jones: It is too low. It should not be that low. Why do you have 0.06? Even 0.15 per cent is no good.

Mr. C. A. McCune, American Chain Co.: Do you find more carbon in the weld at 0.08 than 0.06?

Professor L. T. Jones: No. And at 0.05 per cent you find no more. We analyzed every girth weld for 1000 ft. of pipe and found 0.03 per cent carbon. It is as near pure iron as you can hope to get. In the neutral flame you will find, if you use low carbon, or if you

undergoing pressure test and while it had 400 lb. pressure. It

use any moderate carbon welding rod without something to protect the carbon while the weld is being made, the carbon will be lost. That is why we used vanadium. You must have something, I think, to maintain your carbon during the time it is going in, and I have been unable to find any reason for 0.06 per cent carbon in the American Welding Society's specifications. I don't see any reason why 0.06 per cent is preferable to 0.08 per cent when neither has any bearing on what you are going to get.

Mr. C. A. McCune, American Chain Co.: You are speaking of an alloyed steel with a vanadium content, not a carbon rod?

Professor L. T. Jones: I discussed the rod actually used in the girth welds. It was the low carbon without vanadium. The one we tried and found satisfactory had 0.10 per cent carbon and 0.22 per cent vanadium in the weld metal.

Mr. S. W. Miller, Union Carbide & Carbon Research Laboratories: Might I say a word about welding rod? Some of you who have not been in the welding game as long as I have may be interested to get a little history of this low carbon steel welding rod. When acetylene welding first came to this country about 1904 or 1905, the welding rod used was wrought iron made from billets made in Norway or Sweden. The billets were imported and made into welding rod in accordance with the practice which had been developed in France. Some years later the war came on and it became impossible to get Swedish billets. I happened to know about this personally because I was in the welding business at that time and the people who had furnished me my wrought iron welding rods told me they could not furnish them, but they had a superior quality of steel welding rod. The steel welding rods were made as nearly as possible to meet the physical properties of the wrought iron, which, of course, as you all know, is very low in carbon. The wrought iron wire was a beautiful welding rod because the melted surface was protected by the slag in the rod, which is inherent in the process of the manufacture of wrought iron, and the result was the weld was not burnt. There are other incidental advantages I do not need to go into, in the actual manipulation of the rod.

That is the real reason, in my judgment, for the low carbon steel rod. It was used for years, and used successfully, and is used successfully today for many purposes. I agree entirely with Professor Jones that a welding rod of different composition is very much superior. But there is no reason why success cannot be had with low carbon steel welding rod up to the limit of its capacity.

There are many kinds of welding rods that will give superior results to low carbon steel, but low carbon steel rod will, if intelligently used, give excellent results, and this is a perfecty good reason for the specifications of the American Welding Society including that particular kind of rod. I want to say one other thing.

The chemical analysis of any piece of steel tells nothing about its quality. There are four qualities of plate in ordinary use: tank steel, ship plate, flange and fire-box. The only man that knows the

quality of that steel is the man that makes the heat, and he is the man who classifies it.

There are tests for welding rod that will tell its quality when it is being used, and the specifications of the American Welding Society say that the rods shall perform satisfactorily during the welding operation. If the rod is not of good quality, a good welder can always detect it when he comes to use it in welding.

Mr. J. W. Owens, Newport News Shipbuilding & Dry Dock Co.: The foreman of that job told me that the rods behaved perfectly satisfactorily on the job, and I saw some welds being made, and from all I could see they behaved perfectly satisfactorily in the weld.

Professor L. T. Jones: The welders told me that it did not behave satisfactorily. I believe them.

We did nothing with analysis or determining of the weld metal until the last two weeks of our work, at which time welding was virtually zero. We were occupied, up to then, with the determination of the stresses, with most of which I am concerned, rather than the actual welding. My information on welding is nothing compared with that of many of those present. But the welders previously came to me personally, a number of them, and said: "When are you going to get after this welding rod?"

"What is the matter with it?"

"It is no good."

That did not mean anything to me, so I asked why it was no good.

"It just does not work right. It is dirty."

Dirty! That is part of that other ninety-nine per cent. And you see we have long known that the chemical analysis is not a thing on which one can base judgment. The chemical analysis, or specification, is not the one and only method of judgment. Besides that it must have a small amount of occluded gas. It should have a certain crystal structure in order to flow readily, no excess iron oxide and should not have some other things. That is, it must work well, and this rod apparently was not perfectly satisfactory. Whether it was satisfactory to the foreman or not, I don't know. The foreman, I was told, arranged for its purchase.

Mr. C. A. McCune, American Chain Co.: I am glad Professor Jones is here. I was glad to hear him say what he did on welding rod, because our Welding Rod Specifications Committee have been busy three years proving what Professor Jones has said tonight, and Mr. Miller too. It gives us great pleasure to think that somebody else so far from us has the same thoughts, and the result of our work verifies exactly the statement of Professor Jones that chemical analysis alone does not guarantee a satisfactory welding material.

Professor L. T. Jones: I wish to suggest that the American Welding Society, in conjunction with such other Societies as your Executive Committee may select, communicate with the Directors of the East Bay Municipal Utility District and Mr. A. P. Davis, their chief

engineer, on the possibility of applying gas welding to a selected mile or two miles of the Mokelumne steel pipe in order that we may now once and for all determine whether gas welding is or is not a suitable process for the girth joints of a pipe line of this size.

I make this suggestion realizing fully that the electric welded girth joints that have already been accomplished on the Mokelumne pipe line have amply demonstrated the feasibility of electric welding and that the sole problem which remains is to demonstrate that gas welding will also be satisfactory when carried out under as auspicious conditions as those now afforded electric welding on that particular project.

Welding Research*

C. A. McCUNE†

Welding Research as carried on in our laboratory occupies the attention of five distinct types of people in which are included the

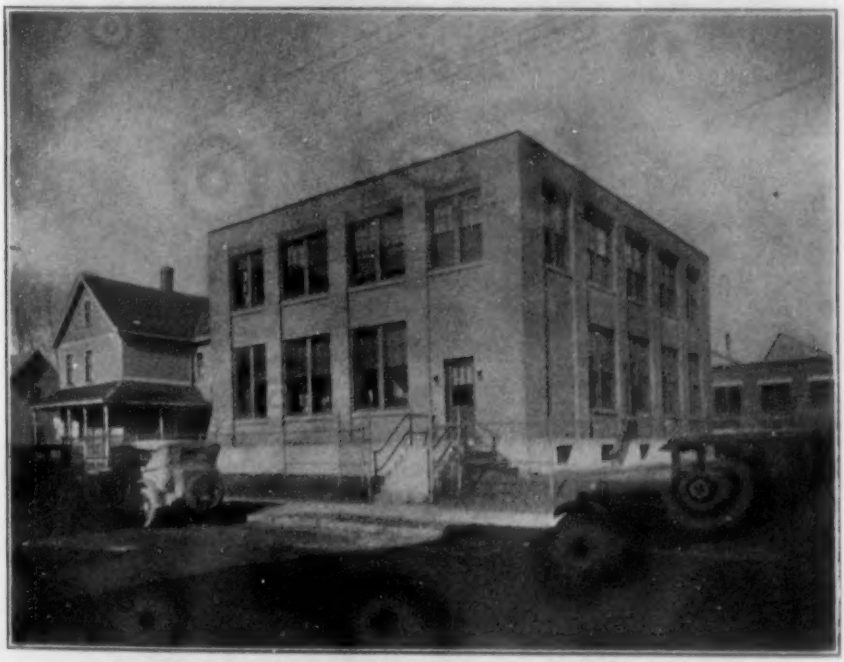


Fig. 1. Research Laboratory, Page Steel & Wire Co.

Engineer, Welder, Metallurgist, Chemist and Physicist, and from the knowledge gained in the last few years the indications are that additional branches of sciences may be effectively applied.

A number of our welding pioneers will not have to stretch their

* Presented at Annual Meeting, A. W. S., April, 1927.
† Director of Research, American Chain Co.

memories very far back to the time when the only instrument available for determining if a weld was good or not consisted of a microscope, vise and hammer, many times the microscope being out of order or missing.

Nevertheless it is to the perseverance of such men that Welding Research has developed to the high plane which it now occupies.

When the importance of welding was fully realized by the larger

Fig. 2. Welding equipment section of the Welding Research Division

industries, no time was lost in placing its study on a sound scientific basis. The effects of research together with the need of superior methods have resulted in a tremendous growth in the use of a process that is recognized the world over as being indispensable.

Research methods of studying welding are in the beginning naturally expensive; the investigations require patience; they are tedious and of long duration; but the results more than offset the initial cost.

This applies equally to the study of the scientific fundamentals, the standardization of materials and equipment, as well as specific applications of the process.

In our own work we have provided as well as we know how for the scientific and practical study of welding both in personnel and equipment. It is evident, however, that only through development and concentrated study of the problem, is it possible to relate

science and practice and create simple test methods that will be of practical value and readily applied industrially.

In other words the test methods as developed from scientific

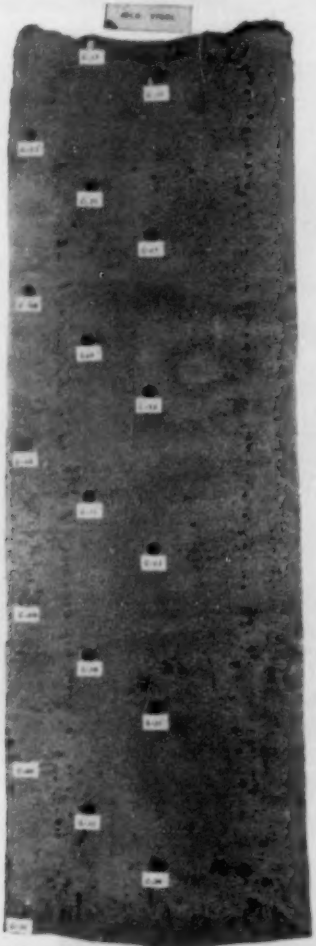


Fig. 3. Cross section of a typical ingot from which ordinary grades of low carbon steel welding wire are made. Over 200% variation in the carbon content alone was found in this ingot

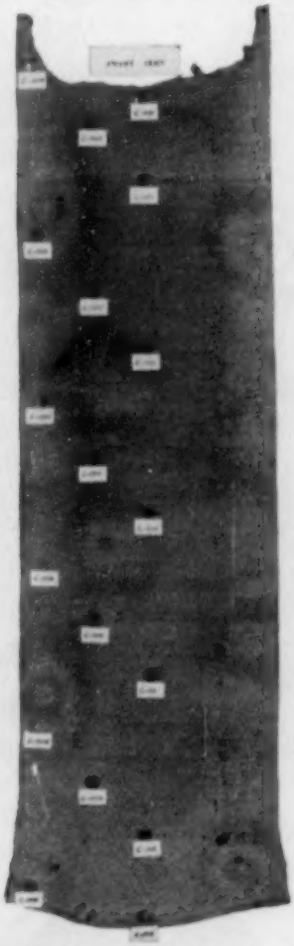


Fig. 4. Commercially pure iron ingot in which the variations are only a part of 1 per cent

research should be such that they do not require a scientist to use them.

In our preparation of welded specimens the actual welding is performed by a responsible welder and supervised by a welder who has served both in the field and in teaching welding. This work is closely observed by either a metallurgist or chemist, depending on the type of investigation under consideration.

The Welding Division equipment includes oxy-acetylene welding

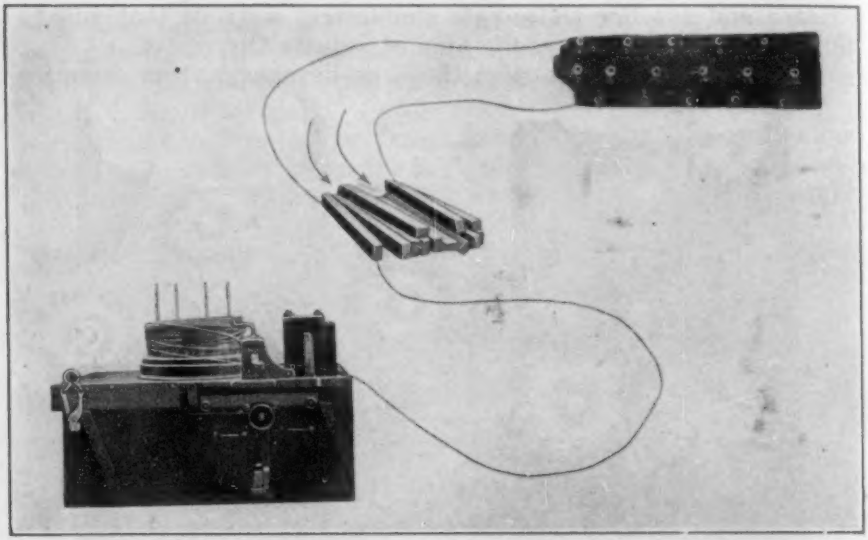


Fig. 5. A non-uniform ingot is capable of producing several "grades" of welding wire, considering the variations in both chemical analysis and physical structure due to the fact that each ingot is rolled into eight and sometimes sixteen billets

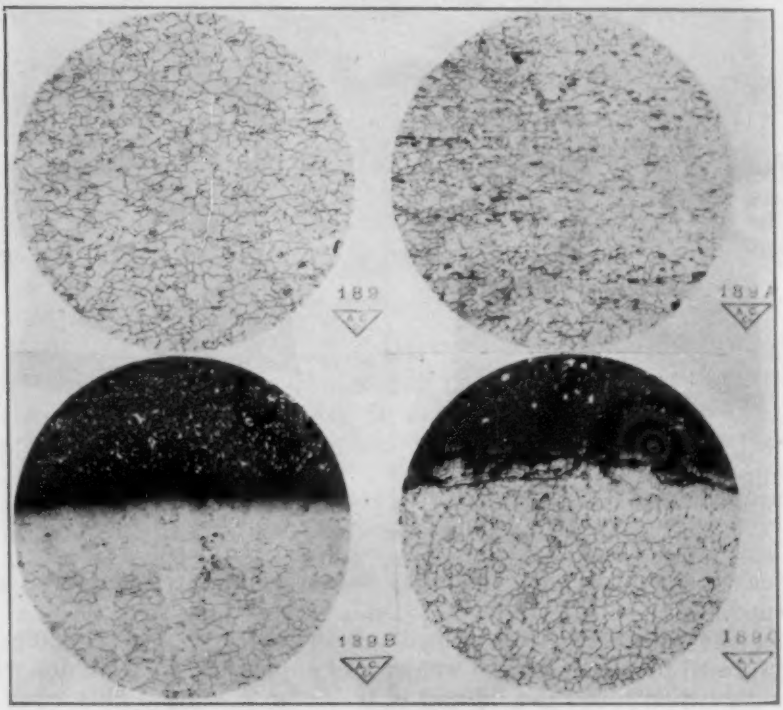


FIG. 6. DEFECTIVE WIRE

This group of photo micrographs are of the same piece of wire and indicate that more than one microscopic examination is necessary before conclusions can be drawn even on one short piece of wire

and cutting torches, electric welding equipment both automatic and manually operated, as well as the Carbon Arc manually operated.

For testing the welding uniformity of electrodes the automatic is preferably used as this eliminates one factor to begin with. Each step in all investigations is under constant observation and

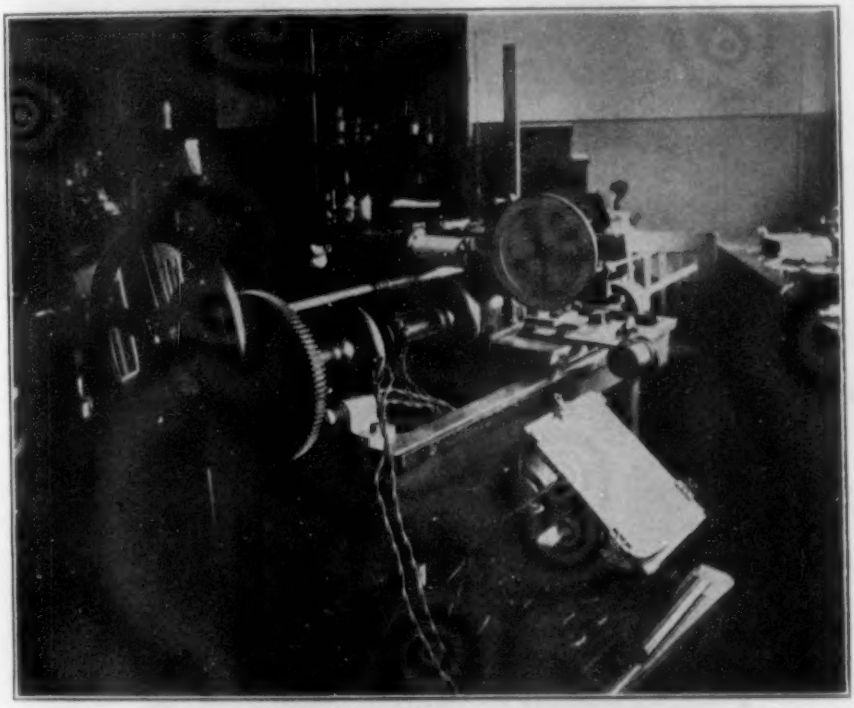


FIG. 7. MAGNETIC METHODS OF TESTING

This is a non-destructive test method for determining the suitability of metal for the purpose intended. It has been fully developed as a Materials Inspection method and has been in successful use on welded tire chains for several years. It is also effectively applied to the inspecion of Welding Wire

all such factors as gas pressures, flame condition, current densities, behavior of metals, etc., are carefully noted.

Due to our very large tonnage of welded chain a separate laboratory is maintained for investigation and study of resistance and forge welding.

The major portion of our work on fusion welding is devoted to the study of the wire used in welding. This involves complete study of metals including their manufacture, reduction into wire, and the behavior of the wire as a welding material.

Commercially pure iron wire is used as the standard by which the welding wire and electrodes are rated.

We are, therefore, compelled to begin work at the furnace, then through the wire mill, and so on down to determinations of the deposited metal.

We have learned long ago that a great many factors are involved in the ingot itself and in the steps between the ingot and the fin-

ished wire, some of our early findings on this subject published several years ago being corroborated by others.

The scientific study of welding has involved the application of magnetic test methods as developed by Mr. deForest. This method

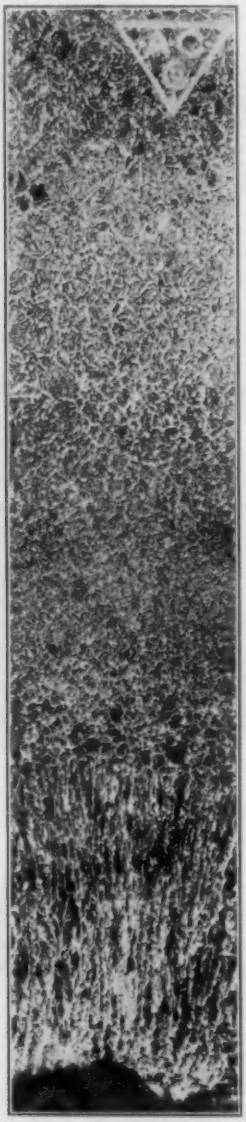


FIG. 8. ELECTRODE STRUCTURE

Showing changes in structure of metal near the welding tip of a used electrode

provides a means whereby stresses and strains in metals and the general uniformity of wires may be determined.

It has also included a study by Dr. Andren of the effect of welding temperatures on metals particularly on metal electrodes, all of which has contributed to the value of chemical and physical uniformity in welding wire and its effect on the weld metal.

We are convinced that without scientific methods little of a definite nature can be assured. We believe that such methods must be adopted to safeguard one of the most important factors in welding, namely, the welding wire.

It is quite common knowledge that Oxygen, Acetylene, Hydrogen, Electricity, Metals, and Welding Equipment have all been developed scientifically. Therefore, it is reasonable to expect that their successful applications in welding must be so founded.

Trend of Fusion Welding Research*

By J. R. DAWSON †

The importance of fusion welding has increased in proportion to its ability to replace other types of joints. It has great advantage in that with a small amount of relatively inexpensive apparatus, perfectly tight joints of high strength are produced and it is successfully applied to all metals and alloys for each of which welding rods of special composition have been devised. Although the use of welding for materials other than steel is of importance, still the greatest interest, particularly from a research standpoint, is in the welding of steel. Until recently practically all steel welds were made with so-called Norway iron welding rods. The greatest tensile strength that can be depended upon with these rods is about 47,000 lbs. per sq. in. for single V welds and 52,000 lbs. per sq. in, with double V welds. Since it should always be possible to have the weld as strong or stronger than the base metal, the demand for a rod which would produce welds of greater strength than the more commonly used low carbon steel base metal resulted in the development of steel welding rods from which 58,000 lbs. per sq. in. tensile strength in single V welds and 63,000 lbs. per sq. in. tensile strength in double V welds could be regularly secured. If such rods were not available, except for the tightness assured, the welded joint would not have much advantage over the riveted joint, but with the high strength which now can be secured, welding has been found more desirable for many important structures than any of the best types of riveted joints.

Although no results have as yet been published of experiments to secure still higher strength, except in the investigations of chrome molybdenum steel for use in airplane construction where heat treated welds have been found to have greater than 100,000 lbs. per sq. in. tensile strength, welds are being made which, without heat treatment, can be depended upon to give a strength of 80,000 to 90,000 lbs. per sq. in. and welds of 100,000 lbs. per sq. in. tensile strength with fair ductility have been secured in the "as welded" condition. The difficulty in the commercial application of this high strength welding is in securing suitable base metal, and the possibilities offered of reducing the weight of vessels re-

*Presented at Annual Meeting, A. W. S., April, 1927.
†Metallurgical Engineer, Union Carbide & Carbon Laboratories.

quired to stand a certain pressure or of increasing the pressures that may be used in vessels of a given thickness make the development of a suitable steel for this welding important. The recent establishment of standard procedure in design, specification and inspection of welds has probably been the most important forward step toward assuring the results that are obtainable in welds and, although persistent efforts will be necessary to secure universal adoption of this method of handling welding problems, much improvement in this direction has already been obtained.

It should not be forgotten that among those interested in the development of welding, research laboratory workers can be numbered in dozens while the users of welding equipment must be counted in thousands and much of the credit for the progress made in the course of the last twenty-five years should be given to these men who developed the process in the field. This may be illustrated by an instance that occurred in pipe line welding where the welders were accustomed to the use of low carbon rods just referred to. The higher strength rods required a different method of manipulation and when tried out, unsatisfactory results were obtained. The supervisor of welding for one of the large pipe line companies in California was not satisfied that the high strength welding rods had been sufficiently investigated for pipe line use. He spent several days practising in alternately making and testing welds in pipes and finally was able to unfailingly produce a weld which could be bent to 180 deg. Then he selected his most progressive welder and taught him the use of the rod. Then, in the regular tests to which the work of all the pipe line welders was subjected, the welder who used the new brand of rod was found to have welds far superior to any of the others, some of whom suggested that they would like to try the rod. Through this spirit of competition, this group of welders gradually came to the point where they were unwilling to have their proficiency judged by the welds that could be produced with the ordinary low carbon rods. It was only through such aggressiveness and careful research work in the field that this improvement in the quality of welded pipe lines was secured.

Extensive investigation by an important California public utility company of welds in pipes from 3 to 12 in. in diameter disclosed a saving in cost ranging from 10 to 29 per cent in favor of the high strength rods. This was due to the favorable flowing qualities of the rod and to the reduction in weld reinforcement required.

The papers presented in this symposium cannot help but impress one with the rapidity of the development of machines for various welding purposes and these machines tend particularly to reduce the cost of the welding operation. The further development of such machines seems certain. These machines and the development of better quality materials for welding rods and the securing of more satisfactory steel for welding, all seem to tend toward the production of welds of improved quality at less cost.

Discussion Technical Papers Presented at Annual Meeting

MORNING SESSION

April 28, 1927

E. H. EWERTZ, *Chairman*

Discussion paper, **"Welding Research of the Newport News Shipbuilding & Dry Dock Company,"** by Mr. J. W. Owens.

Mr. Candy, Westinghouse Elec. & Mfg. Co.: Mr. Chairman, I'd like to ask Mr. Owens if in the welding of plate which has been painted with red lead paint he has discovered any damaging effect on the plates due to the oxidation thrown out in the gas during the welding operation?

Mr. Owens, Newport News Shipbuilding & Dry Dock Co.: I haven't heard any complaint from the operators, but I know it isn't a very pleasant welding job, and for that reason should be avoided whenever possible. I don't think it is necessary to paint the joints if they are well welded.

Mr. Sanborn, Western Electric Company: I'd like to ask Mr. Owens if in his tests on welding galvanized sheets, how much and to what extent the protective coating is destroyed around the spot weld, that is, the surface subjected to corrosion?

Mr. Owens, Newport News Shipbuilding & Dry Dock Co.: I have noticed that the zinc is only locally affected, that is, within the immediate contact with the electrode. It isn't affected beyond that, and the corrosion tests do not seem to indicate that there is any immediate corrosion as a result of the spoilage of the zinc.

There is a point called to my attention by one manufacturer, that where the zinc is not destroyed by the electrode during welding, that the zinc is partly replaced.

Mr. Wyman, General Electric Co.: I'd like to ask what metal was used in welding cast iron?

Mr. Owens, Newport News Shipbuilding & Dry Dock Co.: The cast iron tubular tanks were welded with a gas torch and we found blow holes. We were unable to use welding on the valve seats on account of small blow holes. We tried steel and iron electrodes and tried preheating, but we were unable to eliminate those blow holes.

Mr. Wyman: Blow holes to what extent?

Mr. Owens, Newport News Shipbuilding & Dry Dock Co.: Small holes about the size of an eighth of an inch in diameter, but enough to destroy the utility of the process in so far as you could probably seat valves.

Mr. Crowe, Air Reduction Sales Co.: I'd like to ask Mr. Owens what the difference is in welding those castings and any other cast-iron. We don't find that we get into any difficulty in getting a sound cast iron weld. It is absolutely practical, and free from any blow holes that we can observe with the naked eye.

Mr. Owens, Newport News Shipbuilding & Dry Dock Co.: We had on that particular job one of our best welders, and I feel confident that he is a good man. The fact was that we did get those blow holes and were unable to eliminate them: Now, if any one can describe a technique to me that I can pass across to our practical force, that is what I am looking for.

Chairman Ewertz, Consulting Engineer: Possibly that will be obtained by consulting Mr. Crowe. I think the matter of welding cast iron is very interesting to a great many people, and obtaining a surface which will permit it to be used for a valve or a seat is quite a difficult problem, but if it can be accomplished it will be a great contribution to the engineering world.

Discussion paper, **"Research Activities in the Una Welding and Bonding Company,"** by Mr. R. B. Fehr. (Presented by J. B. Austin.)

Chairman Ewertz, Consulting Engineer: Is there any discussion in connection with this paper?

Mr. Girley: I'd like to ask Mr. Austin if he has had any experience welding steel joints?

Mr. Austin, Una Welding & Bonding Co.: There has been some welding done on it with quite satisfactory results. Where the joints are welded it is customary to back the joints.

Mr. Oehler, Associate Editor Railway Age: I want to ask Mr. Fehr what kind of traffic the welded rail joints on the Southern Pacific were used under?

Mr. Austin, Una Welding & Bonding Co.: These joints I saw were right in the city. I know of no joints that were welded in open track on steam road lines, but there have been some joints on open tracks.

Mr. Lincoln, Lincoln Electric Co.: I would like to ask Mr. Austin what investigation he has made to determine the relative effect of the heavy blow that they use in the testing machine as compared with very much less strain which comes on the joint when it is in use. I understand the testing machine has a blow of 200 pounds.

Mr. Austin, Una Welding & Bonding Co.: 250 pounds.

Mr. Lincoln, Lincoln Electric Co.: That, of course, gives a blow to the joint which is very severe, I should imagine ten or twenty times as severe as the joint would be subjected to in practice by a car passing over it. Judging from the results obtained by the Bureau of Standards on tests of a large number of joints which were welded for the Rail Joint Committee, it seems to me that the heavy blow which was used there was so severe as to not give very much practical information. For instance, there were two sections of solid rail, one of which stood over one million blows and the one next to it about 500,000 blows, and the difference was simply due to the fact that on the 500,000 blow specimen there was a little bit of recess due to a scale being rolled into the rail. That very small scale made a difference of 100 per cent in the recorded result.

Now, as a matter of fact, both of those rails were equally good

for practical use, and would last an equal length of time in practice. I have come to the conclusion that the severity of that test was so great that the conclusions drawn ought to be taken with a good deal of salt. I'd like to inquire if you have any evidence to show that that conclusion should not be drawn from the tests made by the Bureau of Standards.

Mr. Austin, Una Welding & Banding Co.: In our tests we used in the neighborhood of a 35 foot pound blow. A 40,000 pound car going over a rail would cause about that size of blow. The object of the test was to get results as practical as possible.

Mr. Lincoln, Lincoln Electric Co.: If a test was to get the same results in a short time, say in a week or a few days or hours that are obtained in practice, it would be a tremendously important thing. There were some other tests made on the rails by the University of Illinois where a few thousand pound weight was dropped from one foot, two feet, or three on the rail. The conclusions drawn from those tests, I think everybody would agree, were utterly misleading. The joints that would stand the largest number of blows in that test I don't think were necessarily the best joints for railroad operation. I think everybody would agree with that. And the repeated impact test was of the same nature, so severe that it didn't give conclusions which would have special value in designing a joint for operation.

Mr. Austin, Una Welding & Bonding Co.: When we started testing joints about four years ago with a testing machine, the seam started failing at the gap and worked out.

Since we were obtaining the same type of failure they were obtaining in service, we felt that that test was comparable to results obtained in use.

Mr. Lincoln, Lincoln Electric Co.: I quite agree with you if in a test the joints fail the same as in practice you have got a test of value. In the tests which were made by the Bureau of Standards, the failure did not occur where it does in practice, and because it did not occur in the same place it leads me to think that the conclusions drawn from those tests are not accurate.

Discussion paper, **"Research Activities of the General Electric Company,"** by Mr. D. H. Deyoe.

Mr. Edwards, American Bridge Co.: I would like to ask Mr. Deyoe why he didn't use the Bethlehem girder for the top and bottom cord of the riveted section? Then the only difference in comparison would be riveting the web members and welding of the web members.

Mr. Deyoe, General Electric Co.: There is no reason why you couldn't use it, but it isn't being used, that is, the riveting people have not done it.

Mr. Edwards: The reason why is that we are not convinced that you can split with gas and handle those pieces as cheaply as you can when building it up of component parts.

Mr. Owens, Newport News Shipbuilding & Dry Dock Co.: In that case, is it more economical with the gas torch or the carbon arc?

Mr. Deyoe, General Electric Co.: Mr. Chairman, I represent the electrical field, but all of our cutting in our own factories is still done with gas. I think it is more economical at the present time.

Mr. Oehler, Associate Editor Railway Age: I'd like to ask Mr. Deyoe to explain a little more in detail his method of financing the steel ties. He speaks of extending the interest charges over a period of years, but he made no mention of the possible scrap value of the rail which would be available.

Mr. Deyoe, General Electric Co.: That is a very logical question, and it has been very carefully considered by the railroad company. Mr. Loree, President of the B. & O., has acknowledged that the old worn rail has been paid for, and it is worth three-quarters of a cent a pound as scrap, but at the end of its period of use as a tie it will still be worth three-quarters of a cent a pound as scrap. It is an investment that is simply continued over another period of years, and the only thing you can possibly figure is interest on investment. If it is transferred from the scrap department to another, they will want credit, but it is simply a question of bookkeeping.

Discussion paper, **"Structural Steel Welding by the Westinghouse Electric & Mfg. Company,"** by Mr. A. M. Candy.

Mr. Candy, Westinghouse Elec. & Mfg. Co.: In the article which was published in the Journal there were two errors The date for the tests at Carnegie Tech. was 1926 instead of 1925 and saving in steel and waste 95 tons instead of 65 tons; the figure got turned upside down.

In laying out our tests at Carnegie Tech. our principle idea was to get some information before the public in general which would give some impetus to the subject of welding structural steel. We thought somebody had to have the courage of their convictions to make small-sized specimens, ultimately followed with a building of good proportions, and we thought the steel industry would take a great deal more interest in welding than they would if we went along with the slow process which follows getting a great deal of scientific data to give designers sufficient information to complete a design of a building of good size.

It might be interesting to point out there was approximately equivalent to four miles of welding work in that operation and approximately one and one-half miles of welding in the field. A total of 17,000 pounds of welding wire was used in both field and shop, of which approximately six tons were used in shop work and 2½ tons in the field work.

On the entire operation, both shop and field, the power consumed was approximately 37,000 kilowatt hours. We have been criticized by some, I believe, on the basis of hiding the cost in this building. There has been no effort to hide the cost of the operation. The field erection costs line up, so I am told, very closely to the costs which would have resulted if the building had been riveted, and the shop work ran somewhat higher than if the job had been riveted. That is not surprising at all. As a matter of fact, I think in a great many

respects a very good showing was made when you stop to consider the newness of the project, and the fact that the whole scheme had to be worked up from the ground up, as there was very little precedent on which to go.

The field work cost $4.90 a ton. That is the direct charge for power, wire, and labor. The field erection work went forward so rapidly that everybody was agreeably surprised. The entire steel in that 790 ton building went up in five weeks or at the rate of 158 tons a week, or approximately 29 tons per working day, which approximates what is being done in buildings that are riveted. You noticed Mr. Deyoe stated that girders and like designs for welding would show improvement of approximately 25 per cent in reduction of weight in comparison to riveted designs. That is somewhat higher than we obtained in both the 15 foot girders made up for Carnegie Tech. tests, and the two-ton girders, 45 feet long, made up for the Sharon Building.

Chairman Ewertz, Consulting Engineer: We are greatly indebted to the gentlemen who have read the papers to us this morning for the work that they have done in preparing these papers and for the courtesy they have extended us in letting us into some of the inner secrets of this work. Research work is hard to appreciate by some of us practical men, but nevertheless it is through this type of work that the progress is made, and little by little we absorb what originally was research work but which has gradually become a practical application, and then we are very apt to forget just how it started.

If there is any one here who'd like to talk on any subject pertaining to any of the papers that have been read this morning, or any subject on a similar line, we will be very glad to have him come forward.

Mr. Wry, General Electric Company: In connection with Mr. Candy's paper on the hammering of the welds, I wish to say that we have had that same experience with practically the same results.

Mr. Owens, Newport News Shipbuilding & Dry Dock Co.: I was very much interested in the discussion this morning and the papers which related to structural welding. Very few might know that the Navy Department now is constructing six scout cruisers. In those scout cruisers welding is being extensively used, and I think, taking the job as a whole, it is one of the most extensive welding operations going on in the country today. The time is not far distant when not only will our buildings be welded, but our ships will be completely welded. The reason that the Navy Department is pushing it and our Yard and Dry Dock Company is pushing it is that a considerable saving in weight is effected by that process as against the riveting process. In these ships the welding is being used extensively on the decks, in the frames, and practically all piping systems throughout the ship are being welded.

Now, a few years ago, probably four years ago, the only thing you'd find welded on a ship was some small clips, so that within the

last year and a half this remarkable development has occurred in the shipping industry.

Mr. Wolfield: Our work has been in connection with the development or improvements of electrodes, in the study of the plate stock and studying the heat effect of the metal caused by the weld. Principally, some of the effects have been the migration of carbons, which I think is of great importance. I have a few pictures here. We find this migration from the parent stock to the junction of the weld, and with that migration there is a carbonization of the metal immediately behind it. On testing under impact we find the fractures occur through the higher carbon and segregated material and the contention is that it occurs through the decarbonizing material.

This series shows a very fine weld which was made on very fine base material, very high purity. The so-called penetration of that particular weld there was very slight, and I think therein lies the secret of high ductility.

The higher current used the less migration of carbon you get, and also the greater ease of annealling or getting rid of the weld structure. With current densities around 15 to 18 or 20,000 you get structures which can be annealled in about ten minutes, whereas, in the ordinary structure, a commoner grain can't be broken up so quickly.

Here are some welds made by high current on good plate stock after annealing, and the so-called zone of fusion can't be distinguished.

In the ordinary tank pipe or water pipe segregations occur in the manufacture, and during welding due to the stresses set up, the result of the local heat, cracks occur which were found along these low carbon areas and also following impurities.

This set of micrographs shows a weld made on two inch plate with cracks extending back at right angles from the welding through the low carbon area, and one higher power micrograph shows the details.

Mr. A. D. Camp, The United States Aluminum Co.: Practically all the discussion this morning has been on iron and steel. I would like to hear discussed some time in some of the meetings the welding of non-ferrous metal. If you'd be interested I might tell you a few words about what is being done with aluminum in the welding field. High strength aluminum alloys are being applied to many structures where iron and wood is now being used and gas welding is usually employed in the operation.

Work at the U. S. Aluminum Company plant has indicated that we can get welded joints which show from 75 to 80 per cent of the original strength of the metal after the aging process has been applied.

At the Buffalo plant we are welding furniture made out of high strength alloys, chairs, particularly, that are made out of tubular sections and built up channel sections. The welding is all done with gas, and in some complicated assemblies we had trouble at the start

with cracking in the middle of the weld or adjacent to it on account of the solidification during the welding operation. You all probably know that that is what happens, solidification attacks aluminum and alloys and it is about double that of iron and steel. We were able to get around this difficulty by using a 5 per cent silicon, 95 per cent aluminum alloy.

The welding wire has very much less solidification than the base metal, and it also has a very much lower melting point, about 50 degrees Centigrade lower melting point which allows the deposited metal to stay in a semi-molten condition after the base metal has solidified, and the deposited metal then, we believe, fills in the gap like in an ordinary casting.

We have practically no difficulty with cracking of welds with this use in complicated assemblies.

Mr. Swift, American Brass Company: The last speaker has made a very interesting announcement in the use of silicon in welding aluminum. Much work has been done in laboratories recently on increasing the content of silicon in the various alloys. You are all perhaps familiar with the work at Dayton of the Duralumin Company in introducing silicon in larger amounts into iron, and this metal has achieved a very wide use in corrosion resistance work.

We also have taken up a metal that was developed by the duPonts containing a high percentage of silicon in connection with copper and a small amount of manganese to make it workable. It gives us very remarkable results in that we have a copper alloy now whose strength exceeds that of low carbon and even of medium carbon steels, and it is very much like going back thousands of years to the hard copper of the ancients. It has all those qualifications of tensile strength, and in addition to that these metals are very resistant to almost every form of both acid and alkali corrosion.

I have had opportunity to do very little work on these new rods in the form of welding. I doubt very much whether they would do at all in welding cast iron. Here in New York City the New York Edison Company is using these high silicon copper alloys daily in their work on corrosion resisting ducts for carrying off vapors from battery stations, and that is also being done in Chicago and other large cities where they have the large batteries in reserve carrying the loads in the evening when heavy clouds and smoke descend upon the city. I have seen welds that look to me to be very good, although I have not yet had the opportunity of putting them in the testing machine to see what they can do. I have seen this metal deposited on steel at a very great rate. There are often times where it is desirable to deposit rapidly and build up a shaft, and on the steel plate where you'd like to resist corrosion of all kinds.

Now, it would be possible with this alloy to do the work. So far as our welding with the oxygen and acetylene are concerned, we have men in our laboratories who have been hard at work varying the different alloys which are commonly sold such as Tobin bronze and manganese bronze varying but small percentages, but I must

say that as a result of two years of work that they have done they have been quite unable to make any changes that would improve the quality of these old and well established alloys.

It would seem to follow that there are certain underlying physical laws governing these metals which do not change merely because they are put into use as welding rods, and so far we have seen no reason for thinking we are going to improve what we already have in that respect.

Another point that was brought up this morning was on the filling up of holes in gray iron castings. As a rule, gray iron can be welded so it is solid, but in cases where it is cast sometimes for valve seats, some of the nickel alloys serve very well for filling up. We have found that a small introduction of zinc achieves a penetration of the cast iron that is quite remarkable, and it makes it possible to rapidly close up any defects in the casting.

Mr. Burkhardt, Struthers Wells Co.: I am late in getting in, but since this discussion is turning on welding of alloys, I am wondering if there is anybody has mentioned anything about the stainless steel welding, which is an alloy, high chromium steel.

Mr. Holslag, Electric Arc Cutting & Welding Co.: We have tried a lot of stainless steels. There are all different kinds, you know. There is one kind with a copper base and another with nickel and chromium, all marketed under different trade names. They are all a little different and they have to be treated a little differently. For instance, the ones with the copper base weld nicely with the phosphor bronze rod or with the rod made of the same metal as the stainless steel. duPont puts out a rod that will weld copper base stainless steel nicely.

Some of the other chrome-nickel steels can be welded with monel metal and some with manganese. You see, stainless steels are all different, and there is no general rule that will hold; there is no rod that will weld all of them in our experience. You have to try them and see which is the best suited for the purpose. Also, the thickness is an important factor. You have to use a rod that will penetrate as the thickness becomes greater. Then warping enters into it, and it is more or less cut and try in the present state so far as we know.

Mr. Crowe, Air Reduction Sales Co.: I'd like to say that we have had a good many of the stainless steels submitted to the laboratory. When I say stainless steels I mean stainless alloys, some of which could hardly be classed as steels. We had no particular difficulty but succeeded in welding practically all of those alloys, using a welding rod metal of practically the same composition. The difficulty seems to be in handling the material as cracking after the welds have been made sometimes occur. That can practically all be overcome by proper preheating castings or material before welding and taking the proper precautions in cooling.

Mr. Candy, Westinghouse Elec. & Mfg. Co.: I'd like to know whether any of the gentlemen who have spoken so far or any one

else has experience in welding duralumin by any process, and if so, how is it accomplished?

Mr. Camp, The United States Aluminum Co.: I might say Duralumin can be welded successfully. In our work on furniture we have used mostly the magnesium silicon alloy, but we have done some work on duralumin, and I see no reason why duralumin alloy would not weld as well as others. All these alloys are more hot short than aluminum, and in complicated assemblies there is a change. I feel that after our work on this type of silicon alloy that those problems can be satisfactorily solved. We tried all the way from 2 per cent up to 13 per cent silicon and found 5 per cent the best.

Mr. Miller, Union Carbide & Carbon Research Labs.: I wonder whether Mr. Candy wasn't referring to the strength of the duralumin. There is no difficulty about welding, but duralumin is a material that requires a certain heat treatment and ageing afterward in order to retain the high physical properties of it. I think that is what Mr. Candy referred to; the heating of the metal destroys those physical properties, so instead of having a tensile strength of about 60,000 it only has a tensile strength of about 22,000.

Mr. Camp, The United States Aluminum Co.: I think we obtained higher strength than that, Mr. Miller. Tests we have made indicated that we can get from 75 to 80 per cent of the original strength of the alloy. We can get 40 to 45,000 lb. tensile strength in the joint. The breaks nearly always occur one and one-half to five-eighths of an inch back of the weld. Our explanation of it is that the weld itself is somewhat stronger than the metal adjacent to it because it gets a slight heat treating and air quenching operation due to the high temperature in that zone. Somewhere back of the weld there is a point where the metal is not heated high enough to be quenched by the air afterward, and it is partly annealled, and therefore loses some of its original tensile strength, but we can obtain about 75 per cent of the original strength.

AFTERNOON SESSION

April 28, 1927

The meeting convened at 2.10 o'clock.

President Farmer, Electrical Testing Laboratories: The purpose of this organization, as you have often heard read, and as outlined in our Constitution, is the promotion of the art and science of welding. Our activities to accomplish that general object can be almost infinite in number, but the particular type of activity that we want to promote, because it is after all, the thing that is of most material advantage, is the development and expansion of the application of the art. We want to see the commercial application of the art expand into existing fields, and we want to see it ap-

plied in a number of new fields. That is the main spring that keeps this kind of an organization going.

We have for this afternoon a series of papers dealing with special applications of welding in more or less new fields and therefore this series of papers should be of particular interest.

In accordance with our custom, I am going to turn this meeting over to one of our members, in this case, to our vice-president, Mr. Ryder.

Chairman E. M. T. Ryder, Third Avenue Railway System: Gentlemen, I am going to take a little advantage of this opportunity. No one is ever senior vice-president but once, and I am reminded of the situation of the vice-president of the United States, Mr. Dawes, who saw that he once had an opportunity to tell the United States Senate what he thought about them, and he did so. He tried to change that organization from a one man debating society to one which all should take part in.

Now, the suggestions I am going to make are merely from the point of view of those of us who usually sit on the floor and listen to the addresses. We have three hours' time and six gentlemen to speak. We hope to get a discussion from the floor, a good, lively discussion on these various subjects, and I would suggest to the gentlemen who are to speak that if in their papers there are any statistics or there are any formulæ or anything of a nature dry as dust, that they do not read it. Those who care to do so might make their addresses informally, relying on the fact that their papers are published in full or will be, but of course, those who prefer to read their papers as printed have that privilege.

Discussion paper on **"Replacing Castings by Welded Structural Parts,"** by Mr. J. F. Lincoln.

Chairman Ryder, Third Avenue Railway System: There is one thing we all associate with Mr. Lincoln which hasn't been mentioned. We are all very much interested in these splendid prizes that he has offered, and I am going to ask Mr. Lincoln if he won't be good enough to tell us a little about what actuated him and what he hopes to accomplish thereby.

Mr. Lincoln, Lincoln Electric Company: It is right along this same line of the redesign of castings. In other words, the reason for the prize is that there is a tremendous amount of work to be done in order to take advantage of this scheme I have spoken of. For instance, let's take the common every-day base. It is self-evident that you want a base for stiffness, and the natural thing to use would be two or more I beams, because that uses the steel for stiffness.

However, if a base were made up of I beams there would be problems not from the point of engineering, but from the point of view of actual manufacturing. Suppose you have two and tie them together. Almost certainly in drilling you are going to interfere with the web and will have a good deal of difficulty in

holding the base down. Therefore the replacement of the casting with two I beams tied together is not an economical answer to the question. The usual answer is angles or channels which work out very well.

Take the case of a Deisel engine, there isn't the slightest doubt that tremendous economies can be effected and a very much better engine built if steel were used in place of castings. The difficulty of working out the design is very great, although the reward for efficiently solving the problem would be very great, also. Mr. Candy, down at Philadelphia, spoke of the redesign of girders so as to use the metal to the best possible advantage, showing increased strength of the girder by the addition of a small amount of metal welded at the place of maximum stress.

Another case of the same kind, and of very great importance, is the matter of redesigning such a thing as a common engine lathe. The substitution of steel for cast iron would not only result in a very much cheaper and very much better tool, but you could build one which would eliminate the wearing parts or arrange them so that the wearing of the parts would not be an important matter, and could be replaced very very easily. Now it means the entire rebuilding of the tool as soon as its gets out of line.

Because of those problems (and there are thousands of them) the Lincoln Electric Company gave these prizes to the Mechanical Engineering Society, hoping that these various things which should be redesigned, which eventually would be thought of, would be redesigned quickly because of getting interest centered in that way.

Mr. Owens, Newport News Shipbuilding & Dry Dock Co.: Mr. Chairman, the design of fittings and valves offers a big field in redesigning for the use of steel instead of castings. I have just redesigned one which was made of cast steel, but considerable trouble has been experienced in getting uniform solidification. It is a very complicated casting. Our manager, in walking through the shops, called my attention to it and said, "If you want to do something, go and redesign that casting and make it steel." So I have done that.

But when I went to the drafting room to get a design the chief engineer said to me, "I would sooner design a welded boiler than design a throttle valve made of tubing." Nevertheless, I am confident that a satisfactory design can be worked out along that line. The advantage to the user, I think, in the substitution of steel for castings is the elimination of the number of defective castings that you get even with the best run foundry. The casting is completed, sent to the machine shop and machined, and probably not until the last cut has been taken after considerable money is spent in its completion is some defect discovered.

With welding, it is made of standard steel parts, and we know exactly where to look for the defects. We know in general that the steel is fairly uniform, that you are not likely to find defects there, and a defect would be in the weld itself. So then, provided that

there existed a proper organization, you would be assured when the job is completed there would be no more trouble.

Mr. Candy, Westinghouse Elec. & Mfg. Co.: Along the line which Mr. Lincoln has spoken, there is certainly a great deal of food for thought. It is very interesting to see how slow some of the larger manufacturers are to move along lines which are almost obvious. It is always more or less pleasant for some of the young bucks among whom I consider myself, to point out to some of the older persons in the large organizations such as ours, as to where they should substitute welding for riveting.

Welding in the larger established organizations probably doesn't move along as fast as we would expect on account of the older mechanical engineers who have been designing machinery and parts for years, and who are so familiar with rivet designs and designing patterns for castings that it is very hard for them to break away from it.

As an example, one of our designers, a man pretty well along in years, when the question came up of redesigning some of our work, suggested using sheet iron and structural shapes. The designs were worked out on the basis of riveting. In the redesigning, this man couldn't get away from angles for stiffness instead of using simple bar stock. He said it wouldn't look right, and without the rivet heads it didn't look strong enough—so I, in my wild enthusiasm, said, "We will let you make the angles, and we will paint rivet heads, but when we paint them on they are going to be in yellow paint."

I think when we come along to the second generation and get the young men who are having welding preached to them today, the casting Mr. Lincoln spoke of is almost going to be a thing of the past, and it is coming very fast even in some of our larger organizations.

Mr. Holslag, Electric Arc Cutting & Welding Co.: I'd like to speak on some secondary advantages of replacing castings with welding that might not otherwise be mentioned. You know cast iron structures get damaged and break, and cast iron is hard to weld. It is hard to weld, especially by the electric process; you can't weld the steel to it so nicely. But we look forward to the day when castings will be all gone and welded steel will replace castings.

While we are downing the poor old cast iron—you know when a casting breaks they say cast iron doesn't bend. Yet, if you weld a casting together in the original break, right in close contact, it very often is not in line when you get through. The casting may not have bent, but cast iron seems to have a property of giving somewhere else. Some of the cohesion, some of the strength is gone, and there is no way of telling when you make a weld on the part that is broken and strengthen that part up, where it will go next. It will give way somewhere else. That has been very often

my experience. But with steel that bends you can straighten it out and bend it and stiffen it. This will probably be an advantage that we will realize eight or ten years from now through Mr. Lincoln's generosity.

Mr. Ewertz, Consulting Engineer: I think that Mr. Lincoln has come nearer to accomplishing that which we should aim for by giving these prizes than has any other effort that has been put forth been able to do. It is quite natural that most of you gentlemen who are interested in welding as a profession are impatient with the engineers who can't see why they should change their minds and habits just because you come along and suggest it. I am partly of the opinion that we ought to be thankful that we have had a lot of people who have not changed their ideas after they have been thoroughly convinced that they should do it, because ten years ago we were about as enthusiastic as we are today, and it is surprising how little we really did know about welding ten years ago now that we look back and think about it. And yet, we were convinced even then that the engineers in general were very slow and not easy to bend.

Now, by offering a prize, what are you doing? To my mind, you are opening the eyes of the people all around to start thinking about these suggestions of fusion welding. In other words, it is a means of bringing about an education which, after all, is the secret of progress in the use of welding. And while we have as a society attempted in spite of obstacles to produce certain means for educating those uninitiated into the merits of welding, the more spectacular you can make such an appeal to the general engineering fraternity, the more rapid is the education going to be, and I believe that this proposition that the Lincoln Company has offered is going to mean a great deal more than perhaps many other efforts that have been made in the line of education. And after all, gentlemen, this question of the elimination of castings is like many other things—a question of educating an engineer to stop thinking the old way, and stop to think of what he fundamentally wants to accomplish, discarding the methods that tradition has given him which may or may not be of any necessity.

Mr. Crowe, Air Reduction Sales Co.: Along the point of knocking castings, one point occurred to me. During the week, especially in the structural steel committee they have been talking about the variation of the structural steel as a physical property. Some one stated physical properties might vary from a minimum as low as 50,000 to a maximum of 60,000, a variation of about 20 per cent. Now, you take cast iron out of the same ladle, pour a test specimen about one inch in diameter, and you may get a tensile strength of 30,000 to be conservative. The difference in composition will give you anywhere from 20,000 to 40,000.

Take the same thing out of the same ladle and make it six inches in diameter and take a specimen out of the center. You might

get 10,000 lb. per sq. in., which will be getting physical properties from that same heat, with a variation of over 300 per cent.

Discussion paper, **"Production Welding of Stern Frames,"** by Mr. Deppeler.

Mr. Owens, Newport News Shipbuilding & Dry Dock Co.: Mr. Chairman, I didn't expect to talk again, but that stern frame shown by Mr. Deppeler is probably the first new stern frame that has been welded by thermit. I have taken up the question of welding of stern frames before the American Bureau of Shipping and Lloyds with the hope of getting it adapted to the new stern frame construction. The American Bureau is somewhat inclined to consider it but not generally. The chief difficulty, though, is that the ship builder is accustomed to using wrought iron frames, because of its great resistance to corrosion. That might be the chief hindrance to its wider application, but if we can overcome that difficulty I think we would get along all right.

That stern frame is going to be subjected to the worst service that it is possible to put a stern frame to. It is replacing the old one on a ship that will go through the ice floes, so if the weld stands up under those conditions, I don't know where it wouldn't stand up.

Chairman Ryder, Third Avenue Railway System: I might make one further comment on one of the pictures Mr. Deppeler has shown, the welding of the I beam to obtain longer lengths of heavy sections. Some of you may be familiar with the fact that in the subway construction work here in New York City the contractors are allowed a great deal of latitude in the design of their temporary structures to support traffic. They are not allowed to leave the streets open as was done when the first subways were built. They have to provide a structure which will carry a ten-ton vehicle load at any point.

Among the designs used were several which required long stretches of continuous beam. Most of those were riveted designs; but there were places where long stretches of continuous beams, perhaps several city blocks in length, were welded together, and as far as I know were entirely satisfactory.

Discussion paper, **"Application of Arc Welding to Houses and Buildings,"** by Mr. C. J. Holslag of the Electric Arc Cutting and Welding Company.

Mr. Holslag, Electric Arc Cutting & Welding Co.: Mr. Armstrong, from the Electric Welding Company of America, is going to have some photographs of a double decking on a bridge. It seems the bridge is a combination of all structures, and it has even been said to me that some day we will weld a bridge. There are two bridges that I know of now that are welded. One is in Leavenworth, Kan.

Mr. Bates, Philadelphia Electric Co.: I'd like to ask Mr. Holslag a question. In construction—what means were taken of making that building true?

Mr. Holslag, Electric Arc Cutting & Welding Co.: Just the same as a carpenter, right angle measurements. That is another thing

in welding that is easy to do. They weren't always true, but they could be cut and made so. You know, in making a thing like that there is a lot of fooling about it, but we still got it up within the estimate, showing that buildings will be made at half or a third the cost of wooden buildings by welding.

We built an elaborate structure for the duPont people. The first one cost $200, and I was ashamed of taking $80 for the last one. That shows how the cost can be reduced.

Discussion paper, **"Oxy-acetylene Welding of Furniture,"** by Mr. M. F. Bayer of the Simmons Company.

Chairman Ryder: Instead of asking a question, there is one remark I'd like to make. I understand Mr. Bayer confined himself to the bedroom furniture. If he ever gets into the dining room and gets to making the dishes it will be appreciated in my family, because then we can let the small children wipe them!

Discussion paper, **"Application of Welding in Automobile Manufacture,"** by Mr. F. E. Klein.

Mr. Camp, The U. S. Aluminum Co.: Mr. Klein in his paper talked about the removal of flux which he said was very important. In our work on welding aluminum and alloys we have also found that to be very desirable, in fact, imperative if any finish was to be put on such as pointed out, and that was quite an obstacle, when we started manufacturing aluminum furniture. We made quite a study of it and found one method to be very effective, that is by first dipping the welded part into hot water, preferably near boiling point to remove the bulk of flux and then into diluted nitric acid, about 2 per cent. That has a very much higher soluble action on the flux than plain water and removes practically the last trace of the flux. Then follow that with hot water. Any slight traces of nitric acid would not harm the aluminum.

I didn't understand whether Mr. Klein was using acetylene or hydrogen in his welding of aluminum. I think it has been the experience of the Aluminum Company of America that oxy-hydrogen flame is somewhat more suitable than oxy-acetylene. It is a somewhat softer flame, not quite so intense in temperature on account of low melting point of aluminum. Hydrogen flame can be more readily controlled. Acetylene also has a tendency to deposit carbon in the welded area which sometimes retards the cohesion of the two pieces being welded. Tests have indicated that we can get a great number of perfect welds with oxy-hydrogen better than oxy-acetylene.

Mr. Klein: We use oxy-acetylene and the cleaning that we do is done with live steam.

Mr. Camp, The U. S. Aluminum Co.: We have also used it.

The meeting adjourned at four-fifty o'clock.

The Electric Arc and Its Function in the New Welding Processes*

By P. Alexander†

ELECTRIC ARC

The metallic welding arc is a phenomenon of great complexity. It is a combination of three distinct features; namely, conduction of the electric current, melting of the plate and deposition of the metal from the rapidly melting electrode. The first feature in itself is a complicated phenomenon, which can be understood better if we consider it after reviewing the accepted ideas on electric conduction in solid conductors and in vacuum tubes.

The electric current flowing through the solid conductor has been demonstrated by the experiments of Talman and Stewart to consist wholly of electrons. The positive ions form a rigid framework and participate only in the vibratory movements due to the thermal agitation. The whole space is occupied by the spheres of action of the atomic forces. And between atoms there is a continual exchange of the electrons. At any instant there is a number of electrons in transition from one atom to another. These dartings from one atomic system into another are especially numerous in good conductors, and the electrons which during that short flight do not belong to any atomic system are termed free electrons. In the absence of an electromotive force, these movements are equally distributed in all possible directions, and the resultant of those elementary currents is zero. When a difference of potential is, however, impressed on the conductor, these disorderly migrations acquire a certain orientation so that more electrons will be moving in the direction of the positive pole.

An idea of the number of moving electrons may be obtained if we will try to visualize the number 1.6×10^{19} which represents the number of electronic dartings during one second through the cross-section of the conductor when it is carrying a current of one ampere. However great this number may seem, it is not the total number of electronic dartings but only a difference between those directed towards the positive and negative poles.

The conduction through the space not occupied by the solid conductor is electronic only in case of extremely high vacuum. In this case the electrons shoot from the cathode in straight lines across the empty space or through the comparatively few molecules present which in extremely high vacuum can be in the order of a hundred million per cubic centimeter. Since the molecules themselves are mostly an empty space with a few specks representing the central nuclei and outer electrons, the high speed

*Presented at a joint meeting of the Lynn Section, A. I. E. E., and Boston Section, A. W. S., Lynn, Mass., May 18, 1927.

†Thomson Research Laboratory, G. E. Co., Lynn, Mass.

electrons can shoot through them without being stopped or deviated.

The voltages necessary to produce such electronic currents would be of the order of millions of volts and the obtained currents expressed in milliamperes. In other words, for most purposes a space not occupied by either solid or gas of sufficient density is an insulator. There will not be any change in conductivity if a gas in a perfectly neutral state be introduced between the electrodes. The distances between the gaseous molecules, even if their number is increased to several billion of billions per cubic centimeter, are relatively so great that there cannot be any exchange of electrons as in solid conductors between the atoms and the space remains non-conducting. This, however, will cease to be so if the molecules acquire electrical charges.

Under usual conditions gases are subjected to various ionizing radiations such as the radioactivity of the earth, ultra violet rays and the electrons emission from the hot bodies and flames. In atmospheric air these factors determine a generation of two to three ions per second per cubic centimeter. However small the degree of ionization may be, the gas will always contain a few ions and free electrons. If an electron moving with sufficient velocity encounters or passes very near one of the outer orbital electrons of an atom, the repulsive forces between them may be such as to detach the orbital electron from the atomic system, which then remains with a unit positive charge. The removed electron may either repeat the same process with the next molecule or attach itself to it, thereby communicating a negative charge. This removal or attachment of one extra electron to the neutral molecules is called "simple ionization."

Ionized atoms or molecules will also start moving in the direction of the electric force and if the potential gradient is sufficient, will acquire such velocity that their impact on neutral molecules will ionize these. This process of cumulative ionization in a very short time will produce a sufficient number of carriers to transmit from one electrode to another a considerable current. Under certain special conditions, the highly ionized gas column may acquire an electric conductivity comparable with that of a good solid conductor. It might seem strange that a gaseous column can be almost as good a conductor as a copper rod, yet if we remember that the conduction depends only on the number of suitable carriers and on the velocity with which they can move this apparent paradox disappears. To pass now from gaseous conduction to arc conduction, we will consider the effect of the temperature of the cathode.

When the cathode is brought up by some means to a high temperature the electrons will be ejected from its surface into the gas in great numbers. These free electrons can be considered as ions and the gas containing such electrons as an ionized gas. The voltage necessary to move these free electrons towards the anode can be comparatively low. If the gas is at a very low pressure

the electrons will move in straight lines between the molecules. Only a very few of these electrons will be stopped or deflected by collision with molecules. In this case the current will be purely electronic. However, when the molecules are present in larger numbers the electrons (if moving with sufficient velocity) will ionize the gaseous molecules and the current will be carried by ionized molecules as well as by the electrons.

The method of producing the intense initial ionization in the case of an electric arc is by taking an advantage of the property of certain materials to emit at high temperatures electrons which are projected in great numbers from the hot body into the surrounding gas. To draw the arc between the two electrodes, they are brought in contact and a current of sufficient magnitude is passed across the contact. The resistance of the contact, especially just before the moment of separation of the electrodes, is high enough to cause rapid heating of the tips of the electrodes to incandescence, with the result that numerous electrons are projected into the surrounding gas, so that at the moment of separation of the electrodes, the gas contains large numbers of free electrons which under the action of the established electrostatic field will move and impinge on the gaseous molecules.

Since the separation of the electrodes is done gradually, even with comparatively low voltages the potential gradient during the first moment will be sufficient to give the necessary acceleration to the free electrons which at the end of their free path will possess energy to ionize the gaseous molecules. The ionized molecules and electrons will move and impinge on the next neutral molecules but unless the potential gradient is sufficiently high, they will not acquire at the end of their free path a sufficient velocity and consequently will be unable to ionize the next set of molecules; therefore, the ionization will not continue. Since the distance between the electrodes continued to increase and the potential gradient to decrease, the current, after reaching certain magnitude, will fall to a lower value and finally stop altogether. But if the potential gradient during the separation of the electrodes be sufficient, the number of carriers will increase very rapidly until an appreciable current will flow between the electrodes which will produce rapid heating of gas. At higher temperatures the ionization occurs much more readily, so that as soon as the appreciable current flows, the ionization is more pronounced which again causes the current to increase. As soon as the cathode spot on the electrode is brought to a high temperature, a large volume of metallic vapor is sent into the stream which is easily ionized and will conduct practically the whole current. This is the arc conduction.

Since the drawing of the arc is done at a low temperature and the maintaining of the arc at high temperatures, the voltages necessary to strike the arc are always much higher than those used to maintain the arc. This feature is taken advantage of in the design of a number of commercial welding generators which

produce a high voltage only on open circuit. As soon as the arc is drawn, the voltage across the brushes automatically falls to a value only slightly higher than that of the voltage across the arc.

Since high temperature is essential to maintain easy ionization, any factor tending to cool off the electrodes or the arc stream will influence greatly the stability of the arc. If the temperature of the arc falls, the ionization of the materials in the arc stream does not take place as readily, so that the agent producing ionization must be more active. In other words, the speed with which the electrons and ions impinge on the neutral molecules must be higher which necessitates a high potential gradient; that is, higher arc voltage. One of the most powerful methods of cooling the arc core is by surrounding it with hydrogen, which at high temperature dissociates into the atomic state and absorbs large amounts of energy.

Atomic Hydrogen Process

This phenomenon of dissociation of molecular hydrogen at high temperatures into the atomic state was discovered by Dr. I. Langmuir during his studies of the laws of heat losses from a heated tungsten filament in hydrogen at low pressures. Dr. Langmuir observed that above certain temperatures, the heat losses instead of being proportional to 1.9th power of the absolute temperature, are proportional to a much higher power which increases with temperature.

The following studies of this phenomena established that these abnormally high losses are due to the dissociation of molecular hydrogen into the atomic state. Step by step Dr. Langmuir discovered the temperatures of dissociation, degree of concentration of the produced atomic hydrogen, the energy absorbed by the dissociation, the chemical properties of the atomic hydrogen and the thermic effects produced by recombination of the atoms into molecules.

The atomic hydrogen possesses many remarkable properties which have been studied in the last few years by several investigators. Many chemical reactions impossible with molecular hydrogen take place when that gas is in the atomic state. The most stable oxides can be reduced into the metallic state. Substances which are usually considered as the most refractory materials can be melted by the flames of atomic hydrogen. And certain hydrogen compounds which formerly could be produced in very small concentrations, now may be obtained in 100 per cent concentrations. There are two methods of producing atomic hydrogen.

One discovered by Dr. Langmuir is by increasing the speed of the thermal agitation of hydrogen molecules until the forces between the two atoms composing the molecule are not sufficient to hold them together. They spring apart and by doing so absorb large amounts of energy from the source producing that thermal agitation. In this method all molecules subjected to the high tempera-

ture are being acted upon simultaneously. This is (if we can use such a term here) a "mass production."

The other way of disrupting the hydrogen molecule is by hitting it with a heavy atom, moving with high velocity. In this method the hydrogen molecules are dissociated one by one and only when shot with a swiftly moving atom. Using again a shop term, we can call it a "piece work." However, Dr. Langmuir developed the first method which permits the production of atomic hydrogen in high concentration, which permits the use of atomic hydrogen not only as a special chemical reagent but also as one of the most remarkable agents for transmission of thermal energy. To accomplish this, it was necessary to produce the atomic hydrogen not inside of a vacuum container, but in the open air. The method adopted by Dr. Langmuir consists in blowing a stream of molecular hydrogen through an electric arc maintained between two tungsten electrodes.

The temperature of the arc core is sufficient to produce complete dissociation of the whole mass of the gaseous layer in contact with it. The produced atomic hydrogen diffuses rapidly away from the arc core and recombines in the cooler regions into the molecular state, forming an extremely hot flame of a single gas which burns without oxygen. The evolved heat, of course, is the energy previously absorbed from the arc. It was found that the heat of formation of molecular hydrogen is equal to 98,000 calories. In other words, when the atomic hydrogen recombines to produce one cubit foot of molecular hydrogen (measured at N. T. P.), the amount of heat produced is 455 B.t.u. This quantity is greater than that obtained by the combustion of one cubic foot of molecular hydrogen in oxygen. In the last case the amount of evolved heat will be only 316 B.t.u.

The greatest advantage of the atomic hydrogen resides not in the amount of energy transmitted but in the high potential at which that energy is delivered. In other words, the remarkable property of the atomic hydrogen is the temperature of its flame. Dr. Langmuir's calculations show that this temperature is at least 5717 deg. C. One of the experimental confirmation of these conclusions is the fact that tungsten, the metal with the highest known melting point, can be melted in the atomic hydrogen flame but not in any other flame.

The importance of the temperature of the flame can be illustrated by the comparison of two combustible gases; one of which is acetylene and another is propane. The amount of energy produced by combustion of one cubic foot of acetylene is 1456 B.t.u. The corresponding value for propane is 2465 B.t.u.

In spite of much lower heat capacity of acetylene, the temperature of its flame (over 3000 deg. C.) is higher than that of propane (about 2100 deg. C.), and the result of it is that the welding with that gas is much faster than with the latter.

One of the practical applications of the atomic hydrogen flame is for welding of metals.

In this field it has received lately numerous applications on account of its two properties especially valuable for welding work; namely, the extremely high temperature of the flame and the reducing properties of the gas forming that flame.

As a welding tool the atomic hydrogen torch must be compared with the oxy-acetylene torch. It has similar characteristics in that the most of the energy is produced in a comparatively small inner cone or fan where extremely high temperature is attained. This inner hot zone is surrounded by the flame of reducing gas with temperatures gradually falling to that of the outer mantle of the flame where the recombined molecular hydrogen is burning in contact with the air. The temperature of that part of the flame is something like 1000 deg. C.

This gradual change of temperatures gives an extreme flexibility to the atomic hydrogen torch. It insures a perfect control of speed of welding and of the temperature of the molten metal in the weld. This last factor is of a paramount importance for welding in hydrogen atmosphere. This gas is only slightly soluble in molten iron just above the melting point. But with a rise of temperature its solubility increases very rapidly. When the molten iron is overheated, it will absorb at least 15 times its own volume of gas (measured at N. T. P.). During the solidification most of that gas will be precipitated out and unless special precautions are taken, will form numerous blow holes.

However, if the welder follows the right technic by forming only a shallow pool of molten metal which insures a low temperature of the molten iron, hydrogen will be prevented from going into solution and the resulting weld will be perfectly free from gas pockets.

The atomic hydrogen torch embodies in itself all the necessary conditions not only to transmit from the arc into the plate any desired amount of energy, but also to do it at a very high speed. The high speed of recombination of the atomic hydrogen into the molecular state is determined by the steep gradient of temperatures and also by the catalytic action of the metal in the weld.

This recombination of the atomic hydrogen at the surface of the liquid metal in the weld to a certain extent replaces the oxidation reaction always present when the welding is done in air. This reaction supplies the necessary auxiliary heat to keep the surface of the solidifying metal in the molten state long enough to permit the absorbed gases to escape freely.

The a-c. arcs used in the atomic hydrogen process are usually two or three centimeters in length bent in a shape of a fan between two tungsten electrodes placed to form a "V". The voltage drops at the surface of the electrodes, which correspond to anode and cathode drops in d-c. arcs, are equal to about 18 volts each. With the usual arcs of about 100 volts, the 36-volt drop at the

surface of the electrodes, therefore, represents one-third of the total arc voltage, so that two-thirds of the energy absorbed in the dissociation of hydrogen into atomic state comes from the long arc core. The usual arc voltage is about 100 volts and the open circuit voltage of the welding circuit is seldom less than three or four times that value. The energy absorbed by the weld, of course, is that which comes from the arc; the atomic hydrogen plays the role only of an exceptionally efficient transmitter.

The energy evolved by burning the molecular hydrogen in contact with the air, serves only to raise slightly the temperature of the plate outside the weld, but does not affect appreciably the weld itself. Most of that energy is radiated into surrounding space.

The Shielded Arc Process

While the work on atomic hydrogen was proceeding in the Schenectady Laboratory, the writer was engaged in the Lynn Laboratory on the development of an improved method of the arc welding with metallic and carbon electrodes.

Since the accepted explanation of brittleness in arc welds was the presence in the weld of oxides and nitrides of iron, the first experiments were conducted on welding in gases other than those composing the atmospheric air. The first experiments were conducted on welding in carbon dioxide, superheated steam and illuminating gas. Then, without any knowledge of Dr. Langmuir's experiments with atomic hydrogen, the writer came to the conclusion that it is hydrogen which must give the desired results. The experiments immediately confirmed this view. The welds produced in that gas proved to be perfectly ductile and to possess a high tensile strength. Furthermore, it was found that the apparent resistance of the welding arc in hydrogen is more than twice that of the same arc in air. For the reasons of the desirability of rapid deposition of the metal, the welding arc must have a definite short length. The increase of the apparent resistance of the arc without increase in length is most welcome, as it makes the arc almost twice as efficient as a device for the transformation of the electrical energy into the thermal form.

The anode and cathode voltage drops of an iron welding arc of 100 amperes maintained in hydrogen atmosphere were found to be each equal to 16 volts. The voltage drop across the arc stream for an arc of $\frac{1}{8}$ inch does not exceed 5 volts, so that the total voltage across the arc of $\frac{1}{8}$ inch in length is 37 volts. The usual arc voltage of the welding arcs of the same length and current intensity maintained in air is about 18 volts.

This abnormal apparent resistance of the arc in hydrogen, the writer at that time attributed to an exceptionally high coefficient of heat conductivity of that gas. Indeed, the heat conductivity of air is 0.5×10^{-5} and that of hydrogen is 3.17×10^{-5} calories per centimeter per second per deg. C. In other words, it was thought

that the high voltage of the arc is due to a mere cooling of the arc by hydrogen in its molecular form.

At a later date, to check up this assumption, the writer repeated the same experiments with the arcs in helium. This gas has also an exceptionally high coefficient of heat conductivity which is even slightly higher than that of hydrogen; namely, 3.39×10^{-5}. The experiments, however, showed that the arc voltage in that gas is lower even than in air. Since the coefficients of diffusion of hydrogen and helium are about the same and the temperature of the arc core in both cases probably does not differ materially, the only explanation of difference in the arc voltages was that the hydrogen, being a diatomic gas, was dissociated into the atomic state while the helium, being a monatomic gas, remained unchanged by the extreme temperature of the arc.

These experiments have an interest only as illustration of various ways of investigation. The quantative determination of the amount of atomic hydrogen produced cannot be based on such experiments. They only demonstrate the fact of the dissociation of hydrogen into the atomic state and that it affects very markedly the anode and cathode fall.

These two quantities are determined by the concentration of the ions of one sign at the surface of the electrodes. If the production of the ions of the other sign in the first gaseous layers next to the elctrode is slowed down, the electrostatic charges of the incoming ions will determine a very steep potential gradient. The dissociation of hydrogen into the atomic state cools off the surface of the anode and cathode and, therefore, reduces there the speed of ionization and emission of thermions. The role of atomic hydrogen in the shielded arc process can be compared with the most effective means of cooling the electrodes.

Of course, the atomic hydrogen produced undoubtedly affects also the quality of the weld, making it more free from oxides. This last action, however, is not as important as that which increased the efficiency of the arc, since in the shielded arc process the weld is fully protected by a large volume of the molecular hydrogen which at the high temperature of the arc is also one of the most energetic reducing agents.

The Deposition of Metal

The transfer of the metal from the electrode to the plate can be either purely ionic or mechanical. In the first case the metal is rapidly vaporized from the electrode, enters the arc and after being ionized is moved across the arc to the surface of the positive crater where it regains its state of neutral atoms and condenses as a vapor on the surface of the crater. The speed of motion of gaseous ions is very high so that large quantities of metal can be transferred from the electrode to the weld in a very short time. The hypothesis of transfer of the metal in the state of vapor

has been advanced by Professor Slocum. This type of metal transfer is observed only with long arcs.

The writer's experiments indicate that the temperature of anode is the determining factor in the ionic transfer of the metal in the welding arc. If an arc of 125 amperes and 60 volts be maintained in hydrogen between a cold plate and ⅛-in. Armco pure iron electrode, the transfer of metal will be mostly mechanical. The tip of the electrode will be liquefied and the large drops of metal will be periodically falling down on the plate. The vapor stream from the negative electrode will enter the arc, but there will not be appreciable condensation of that vapor on the plate. If, however, the positive crater will be allowed to establish itself on the plate and the temperature of the molten metal in the crater will rise above certain limit, then the arc will become very stable and practically the total amount of metal will be passing through the arc in a state of ionized vapor. The speed of "vapor deposition" of metal is about the same as that which would be with the short arcs of the same current density when practically the total amount of metal is passing through the arc in the liquid state. However, in usual practise, the arc length is so short that the intense radiations from the positive crater affect not only the surface of the negative crater, but also the whole tip of the electrode to a considerable length. This results in rapid melting of the tip of the electrode which is in more or less plastic state to a distance of three or four milliameters from the negative crater. This condition determines an entirely different mode of transfer of metal across the arc. The wire used as electrodes always contains a large amount of occluded gases. The actual volume of occluded gases depends on the method of manufacturing of the wire, and in certain instances may reach many times the volume of the metal.

The amount of gas which the metal can hold in the occluded state depends on the temperature. At the temperature of red heat, most of the gases are expelled from the metal. Since the tip of the electrode is in molten state, it is mechanically the weakest point and the gases escape in that direction, which results in periodical rupture of the liquid surface of the tip of the electrode and projection of it into the direction of the positive crater. If the arc is very short, this ruptured part of the tip of the electrode short-circuits the arc. In other words, it bridges the tip of the electrode with the positive crater. As soon as the globule touches the liquid surface, another set of forces comes into play; namely, the surface tension of the molten metal. Now the globule is pulled towards the liquid by the surface tension and so breaks the contact with the electrode. If the time of transfer was short, the temperature of the ionized gases was not affected appreciably, so that the arc can be readily restarted. The experimental proof of this mechanism of transfer of molten metal across the welding arc was furnished by many investigators, amongst whom we must name Professor Hudson, who advocates the theory of liquid trans-

fer of metal determined by the expulsion of the gases, and O. H. Eschholz, who demonstrated that even without the explosive action of gases, the metal can be transferred through the action of the forces of the surface tension. However, the writer is of the opinion that both types of forces are responsible for the transfer of the metal in the short welding arc.

Physics and Chemistry of the Crater

In the case of arc welding with a metallic electrode, the positive crater is established on the plate itself. This is the most efficient method of transmitting the energy of the arc into the plate. In this case not only the metal is subjected to the radiations from the negative crater and the arc core, but it is also the subject of the most terrible bombardment by the electrons and ions rapidly moving toward the anode. The velocity of gaseous ions in the arc core is not definitely known, but it may be expected as being very high. Furthermore, the condensation of the gaseous ions on the liquid surface of the crater is accompanied by the evolution of the latent heat of evaporation of electrons and gaseous atoms. This last factor explains the difference in the calorific effects at the anode and cathode of the arc in spite of the fact that the anode and cathode potential drops, as in the case of the iron arc in hydrogen, are the same. The surface of the metal is heated so rapidly that the heat has no time to be conducted away through the thickness of the metal. Therefore, the metal around the foot of the arc core is liquefied and forms a shallow molten pool. The metal in this molten pool is a subject of several actions. First, the rapidly falling metallic globules splash the molten metal so that the surface of the crater is continually swept by the waves running from the center of the crater to the periphery. Secondly, the molten metal, being free to move, is repulsed from the foot of the arc by the electromagnetic interaction of the currents carried by those parts of the arc and moves toward the edges of the molten pool, forming a sort of a shallow cup or a crater.

The absorption and evolution of gases in different parts of the crater is a factor of paramount importance. The accurate tests conducted by Dr. Baraduc-Muller, who was experimenting with the masses of molten steel weighing 11,000 pounds, demonstrated that molten steel may hold in solution very large amounts of gases. For instance, the volumes of hydrogen, carbon monoxide and nitrogen occluded in one cubic foot of molten Bessemer steel are respectively equal to 13, 8 and 5 cubic feet (measured at N. T. P.).

The writer's experiments with hydrogen, helium, argon, carbon monoxide and nitrogen occluded in the molten part of the crater gave about the same figures and indicated that these gases are precipitated out from the molten steel when it is still fluid. The observation of the large craters of the powerful arcs burning in different gases reveals that all these gases are absorbed in the hot part of the crater and evolved in a form of a stream of bubbles

coming to the surface of the molten metal in cooler parts of the crater.

This continual process of absorption and evolution of gases is equivalent to an energetic washing of the molten metal with hot gas. The occluded gases may react with the metal and form nitrides, oxides, hydrides, or may simply be held in solution and be partly precipitated out during the solidification. At any rate, the large amounts of absorbed and later evolved gases have a very great bearing on the soundness of the deposited metal and the number of blow holes which it may contain.

When the arc is maintained in air, the fundamental chemical reaction in the crater of the arc is oxidation. Oxygen of the air coming in contact with the molten metal reacts almost instantaneously and forms Fe O, which is gradually dissolved in the mass of the metal. The excess of that oxide floats on the surface in a form of a slag and being further oxidized during the freezing of the metal to the $Fe_3 O_4$. The oxidation or burning of the surface layer of the molten metal in the arc crater has a determining influence on the number of gas inclusions in the weld metal. As has been demonstrated by the writer's experiments on welding arcs in argon-oxygen mixtures,[2] the amount of heat produced by the oxidation reaction is sufficient to maintain the surface of the freezing metal near the edge of the crater in molten state long enough to allow all the gases to escape freely and leave the weld metal free from blow holes.

When the deposition of the metal is done in reducing or neutral atmosphere, this reaction is suppressed, and unless special precautions are taken, the weld metal will contain numerous blow holes.

It may be pointed out here that in the atomic hydrogen process the recombination of the atomic hydrogen into the molecular form at the surface of the weld metal provides a source of large amount of energy. In this way the atomic hydrogen process not only suppresses the deleterious action of oxidation, but also provides means to replace the important and desirable influence of that reaction by a new reaction which takes place of the old one. In the shielded arc process, other means are used to assure the prompt expulsion of the occluded gases.

Welding in Mixed Gases

The development of the shielded arc process extended also to the making of welds in mixtures of hydrogen and carbon monoxide according to the ideas of Prof. E. Thomson.

The tests demonstrated that the metal deposited in that atmosphere possessed about the same ductility as those produced in pure hydrogen. Furthermore, it was found that the arc in water gas

[2] Oxidation of the arc crater. The *Journal* of the American Welding Society, December, 1926.

is much more stable than in hydrogen and does not necessitate the open circuit voltage even for welding with comparatively low currents, higher than used for standard work of welding in air.

Other tests were made with various gaseous mixtures. In conjunction with Professor Thomson, the author found that not only various mixtures of hydrogen and carbon monoxide could be used for welding work, but that certain organic liquids such as methanol and denatured ethyl alcohol when vaporized will serve the same purpose as the pure hydrogen.

Working in conjunction with Dr. Langmuir, the author also carried out a series of tests which demonstrated that for certain purposes nitrogen mixed with certain amounts of hydrogen gives welds of superior quality. It should be mentioned here also that the mixture of hydrogen with argon was suggested to the writer by Mr. P. K. Devers.

The work conducted on welding in various gases resulted in the development of practical means of producing these gases easily and at a low cost from various organic and inorganic compounds, such as alcohols, ammonia, propane, etc. Since these compounds are liquids or liquefied gases, the question of storage and transportation has also been solved. This can be made clear if we consider that one gallon of methanol will give on vaporization and dissociation in the arc over 240 cubic feet of gas. The development of welding in alcohol vapors should be especially emphasized as one of the most practical solutions found in this laboratory of the problem of storage and cost of the most suitable gas for welding by the shielded arc process, which is water gas.

When instead of pure hydrogen, the shielding gaseous atmosphere is provided by the gaseous mixture of carbon dioxide with propane or the vapors of alcohol, the function of the arc is not only to liberate sufficient amount of energy to melt the metal, but also by dissociating the gaseous raw materials produces a suitable mixture of hydrogen with carbon monoxide. The electric arc here becomes not merely a source of heat but also a chemical laboratory.

If we try to visualize all that is happening in the small space occupied by the arc, all the different chemical reactions, transformation of electrical energy into thermal form, absorption and evolution of gases and the deposition of metal, one begins to wonder how it is possible for the welder to take care of all these complicated factors. The answer is that they take care of themselves. If the conditions are regulated rightly, all these processes are entirely automatic and the man has to watch only the needle of the meter.

After going through this description of the atomic hydrogen and the shielded arc processes, one may ask, "What is the purpose of this development? What is all this for? Is it easier to use a

combination of the electric arc with the gas instead of using each of these factors singly?"

The answer to the last question is "no." Of course, the combination of several factors necessitates better technique and more accurate adjustment of all the conditions. But what is complicated today will be a simple thing tomorrow.

It is simpler to make a lamp with the tungsten filament in the vacuum than a combination of the same filament and the gas. But who wants now the older and simpler type of the incandescent lamp? The present arc welding processes are all right and give excellent results in every field of their applications. But so did the rivet thirty years ago.

There was a time when no one dreamed of using anything but pure wrought iron. Then there came an age of iron-carbon alloys; that is, of steel. And now we are entering the era of alloy steels. Most of those steels contain such easily oxidizable elements as chromium. And unless the weld is protected by a reducing atmosphere, the results on welding such materials are not satisfactory. It is in this field that the new processes probably will find their best applications.

The electric arc and the gas flame will in the future replace rivet cutting tools and the foundry mold. Amongst innumerable fields of applications there will be demand for every kind of welding and cutting processes. The described processes will not replace any of the existing processes, but simply assume their place of usefulness amongst the older brothers and do the job which cannot be done without their help.

CURRENT WELDING LITERATURE

All Welded House Heating System. Acetylene Journal (May, 1927), Vol. 28, No. 11, pp. 512-514. The experience of a home owner who tried welding shows that welded joints save money on installation.

Application of Welding Art to Building Interests Society. Electrical World (May 7, 1927), Vol. 89, No. 19, p. 980.

Arc Welding Structural Steel Buildings. C. G. Watson, Iron & Steel Engr. (March, 1927), Vol. 4, pp. 151-64.

Are Oxyacetylene Torches Back-Firing? The Australian Welding Engineer (April 1, 1927), Vol. 1, No. 4, pp. 73-76. A controversial subject.

Automatic Arc Welding. Digest (April, 1927), Vol. 7, pp. 11-15. Arc Welding of Cylindrical Containers.

Committee on Welded Rail Joints. Progress Report No. 4 on Repeated Impact Tests. July, 1926. 35 pp. Includes tests on electric resistance, electric seam and thermit welded joints.

Electric Arc Welders Used in Willys-Knight Body Assembly Line. Automt. Ind. (April 16, 1927), Vol. 65, p. 595.

Electric Welding of Tank Seams (May 7, 1927), Vol. 89, No. 19, pp. 967-8.

"Light" from the Welding Torch. Part II. Edward Louden, Automobile Digest (March, 1927), Vol. 15, No. 3, pp. 23-26. Manipulation of the torch. Care of the torch. Preheating. Welding steel, malleable iron, brass, aluminum and sheet metal. Qualifications of a welder.

Lincoln Machine-Driven Carbon-Arc Welder. Power (May 17, 1927), Vol. 65, p. 757.

of this development? What is all this for? Is it easier to use a

Lincoln Arc Welding Machines Made of Welded Steel. Power (May 10, 1927), Vol. 65, p. 719.

Miller Medal Established as Welding Award. Power (May 17, 1927), Vol. 65, No. 20, p. 761.

New Orleans Develops Device to Conceal Arc in Rail Welding. J. J. Wymer, M.D.A.E.R.A. (May, 1927), Vol. 17, No. 4, pp. 553-555.

Oxyacetylene-Welded Construction of a Large High-Pressure Storage Tank. H. E. Rockefeller, Mechanical Engineering (May, 1927), Vol. 49, No. 5, pp. 405-411. Design of Tank. Selection of Material. Preparation of the Parts for Welding. Welding Girth Seams. Welding Saddle Plate to Manhead. Providing Ventilation. Test of Tank. Design of New Manhole Reinforcing Ring. Welding New Manhole Reinforcing Ring to Manhead.

Penetration. G. A. Whiting, The Australian Welding Engineer (April 1, 1927), Vol. 1, No. 4, pp. 71-72.

Pipe Welding Possibilities. Acetylene Journal (May, 1927), Vol. 28, No. 11, p. 528.

Practical Oxyacetylene Welding. VII. R. Granjon, P. Rosemberg and A. Desgranges, The Welding Journal (April, 1927), Vol. 24, No. 283, pp. 109-112. Chapter 12—Notes on the Oxyacetylene Welding of Steels. Chapter 13—Notes and Exercises on the Welding of Cast Iron.

Principles of Pressure Vessel Welding. H. E. Rockefeller, Acetylene Journal (May, 1927), Vol. 28, No. 11, pp. 507-511 and 518. Details of Procedure Adopted for Oxyacetylene Welding of a Gas Tank 43 Feet Long to Stand a Pressure of 300 Lbs.

Production Welding of Sheet Metal. Acetylene Journal (May, 1927), Vol. 28, No. 11, pp. 519-520 and 524. Growing Use of Sheet Steel for Permanence of Service Is Accompanied by Large Fabrication Economies Through Welding.

Stelliting Dredge Cutters. Pacific Marine Review (May, 1927), Vol. 24, No. 5, p. 236.

Structural Steel Welding. The Australian Welding Engineer (April 1, 1927), Vol. 1, No. 4, pp. 76-77.

The Design and Construction of Pressure Vessels—II. L. J. Sforzini, Power (May 3, 1927), Vol. 65, No. 18, pp. 670-674. Modern Practice in Seamless and Welded Construction.

The Most Important Thing in Welding. S. W. Miller, The Australian Welding Engineer (April 1, 1927), Vol. 1, No. 4, p. 78. 1, Design. 2, Materials. 3, Methods. 4, Operators. 5, Supervision. 6, Tests.

The Welding of Cast Iron. P. L. Roberts, The Welding Journal (April, 1927), Vol. 24, No. 283, pp. 102-106. A discussion of this paper.

Welded Steel for Machine Bases. Mechanical Engrg. (May, 1927), Vol. 49, No. 5, p. 413.

Welding of Thin Metal Sheets Without Tacking or Welding wire, The Welding Journal (April, 1927), Vol. 24, No. 283, pp. 118 and 123.

Welding Facts and Figures—XII. D. Richardson, Wh.Exh., A.M.I.Mech. E., and E. W. Birch, A.M.I.A.E., The Welding Journal (April, 1927), Vol. 24, No. 283, pp. 113-116. Handbook for Welding Engineers.

Welding in Plant Construction Indicated by Progress. Power (May 3, 1927), Vol. 65, No. 18, p. 686.

Welding Plate of Medium Thickness. Acetylene Journal (May, 1927), Vol. 28, No. 11, pp. 521-524. Preliminary exercises which aid the welder to acquire proper skill necessary for successful tank welding.

Welding Society Discusses Developments of Art. Engineering News-Record (May 5, 1927), Vol. 98, No. 18, pp. 741 and 745.

Welding Society Holds Its Eighth Annual Meeting. Power (May 3, 1927), Vol. 65, No. 18, p. 687.

Lincoln Machine-Driven Carbon-Arc Welder." Power (May 11, 1926), Vol. 65, p. 757.

TRAINING COURSES

IN order to meet the evergrowing demands of the welding industry for authentic instruction books for welders, an Educational Committee of the American Welding Society has compiled training courses for electric arc, gas, resistance and thermit welders.

The thermit course is the first of these bulletins and is printed as a supplement in this issue of the Journal. Separate copies are available in bulletin form at a price of 50c per copy. The other courses will be available within the next few months. Orders may be placed now.

AMERICAN WELDING SOCIETY
33 West 39th Street
New York, N. Y.

Special Prices for Quantity Lots!

YEAR BOOK

AMERICAN WELDING SOCIETY

THE Second Year Book of the American Welding Society will be published as the August, 1927, issue of the Journal. Last year the membership directory of the American Welding Society included many important items of information concerning the work of the Society and its committees. The directory of membership is really regarded as a blue book of the welding industry in that it contains the names of the most important people identified with welding developments.

The Membership Committee respectfully suggests that every member of the American Welding Society make an effort to secure at least one new member on or before July 15th in order that as many new members may be included in the Year Book as possible. A copy of the old Year Book and sample copy of the Journal will be sent upon request.

AMERICAN WELDING SOCIETY

33 West 39th Street

New York, N. Y.

ACETYLENE JOURNAL

Established 1899

A monthly publication devoted to gas welding and cutting and other uses of the gases produced by this Industry.

If you are engaged in gas welding, or interested in any capacity in the Industry, you ought to be a reader of the ACETYLENE JOURNAL.

Its reading pages are **all** devoted to the promotion of **your** business. They will **help** you solve the many problems in repairing broken machinery, manufacturing new articles, and increasing production in your plant. It is edited and contributed to by the best authorities in gas welding and cutting. Should you have difficulty on any welding job, a letter written to the editor describing the trouble will bring you immediate advice.

Subscribe Now. Get in touch with the developments of the process and the benefits derived therefrom. Subscription price $2.00 a year.

A sample copy will be mailed on request

G. H. MATHEWS, Managing Editor

ACETYLENE JOURNAL PUBLISHING COMPANY

53 W. Jackson Blvd. **Chicago, Ill.**

Member Associated Business Papers, Inc.

The Welding Engineer

Member Audit Bureau of Circulations

FOUNDED BY L. B. MACKENZIE, 1916

"Take the Guess Work Out of Welding"

AN old slogan around the office of *The Welding Engineer*, but still one which cannot be emphasized too much. In your plant there is a man who needs timely, accurate and practical information about welding. See that he gets *The Welding Engineer* regularly. Subscribe now.

No matter what your welding problem may be, *The Welding Engineer* is the best source of information available. Its pages discuss, monthly, every phase of welding. One idea from one issue will more than pay for a year's subscription to this valuable publication. The value of the reading matter is assured for the best welding authorities in America are regular contributors.

Arc Welding, Electric Butt, Spot and Seam Welding, Oxy-Acetylene and the Thermit System, in fact every known process of joining metals is discussed. Our Buyers' Index reflects the progressiveness of America's first manufacturers.

Price $3.00 in the United States and Canada; $4.00 Abroad

Sample Copy Sent Free Upon Request

H. S. CARD, EDITOR

The Welding Engineer—608 S. Dearborn Street, Chicago, Ill.

MEMBERSHIP APPLICATION BLANK

AMERICAN WELDING SOCIETY

33 WEST THIRTY-NINTH STREET
NEW YORK, N. Y.

.....192..

Secretary:

I hereby apply for Class.....Membership in the .....Section of the AMERICAN WELDING SOCIETY and attach hereto remittance of $..... for first annual dues. Remittance will be refunded in the event of rejection of applicant. I also agree to abide by the Constitution and By-Laws of the Society and By-Laws of the Section.

Name .....

Present occupation .....

Name of Company and Address .....

Residence .....

Address for mailing .....

.....

.....

.....

.....

.....

Applicant is requested to state here length of welding experience and processes involved, also to record any technical or mechanical experience.

References: (1. .....

(at least two) (2. .....

Proposed by .....

(See other side)

CUT OFF ALONG THIS LINE

QUALIFICATIONS FOR MEMBERSHIP

Extract from By-Laws

ARTICLE I.

Section 1. Individuals having received the approval of a majority of the Membership Committee shall become members of this Society upon the payment of dues, except in the cases of honorary members who shall be elected by unanimous vote of the full Board of Directors.

Section 2. Membership shall be divided into five classes:

Class A. Sustaining members, being individuals or individuals delegated by corporations, firms, partnerships, etc., interested in the science and art of welding, with full rights of membership.

Annual dues..... $100.00

Class B Members, being individuals interested in the science and art of welding, with full rights of membership. Engineers or individuals competent by experience or training to plan or direct welding operations are eligible to this class.

Annual dues..... $20.00

Class C Associate members with right to vote but not to hold office, except in Sections as may be provided for by the By-Laws of the Section. Supervising welders, inspectors and skilled operators, with three or more years' practical experience in welding, are also eligible to this class.

Annual dues..... $10.00

Class D Operating members, who are welders or cutters by occupation, without the right to vote or hold office except in Sections as may be provided for by the By-Laws of the Sections.

Annual dues, United States and Canada $5.00
Other countries..... $10.00

Class F Student Members, who are actually in attendance at any one of the recognized colleges and approved trade schools, without the right to vote or to hold office except in sections as may be provided for by the By-Laws of the Section.

Annual dues..... $2.50

TORCHWELD LEADERSHIP

"Standard of Comparison"

Torchweld is the acknowledged leader in the gas welding and cutting equipment field because Torchweld design is original and Torchweld superior construction insures long and satisfactory service.

TORCHWELD EQUIPMENT CO.

224 No. Carpenter St. Chicago, Ill.

If You Want to Know Why

REGO

OXY-ACETYLENE EQUIPMENT

Gives more satisfactory service. Operates with a lower gas cost. Costs less to maintain *than any other equipment—*

Write for Booklet - "FACTS"

THE BASTIAN-BLESSING CO.

252 E. Ontario St. Chicago

Weldite

Welding Rod

WELDITE G—No. 6 Coppered Finish for gas welding lays the metal down quietly, free from boiling, free from surface scum and floating white specks. The metal settles instantly when the torch is removed.

WELDITE E—No. 18 Green Surfaced for electric welding is the smoothest running electrode ever offered users of welding. Sold at the price of bare electrodes.

Products of the Research Department

Weldite

MANUFACTURED BY

CHICAGO STEEL & WIRE CO

103rd Street *and* Torrence Avenue CHICAGO

Left: Operator at work on one of the 16-inch steam risers. *Center:* Main riser with five manifolds, showing 8-inch welded connections. *Below:* 16-inch flange, welded on both sides of expansion joint.

Why WILSON Welding Wire *was chosen for the* Ohio Bell Telephone Building

BEFORE Smith & Oby, Cleveland, plumbing and heating contractors and engineers, started to weld the steam risers that feed fifteen stories of the Ohio Bell Telephone Building, in Cleveland, they made test after test in the laboratory to find the welding wire they could depend upon to *hold*. Pieces of 8" pipe were butt-welded, test coupons were cut, and then pulled and bent—the coupons were all machined flush, and welded with the same machine and by the same operator. *In these tests the welds made with Wilson "Color-tipt" Welding Wire were the only ones that broke outside the weld.*

That is why Smith & Oby selected Wilson Wire for *every weld on the job*—for every weld on the 16-inch riser that extends through fifteen stories, and for every weld on the distributing risers that feed up and down from the fifteenth floor. Wilson Grade No. 6 (Patented U. S. A., June 13, 1916; March 9, 1920; Canada, March 19, 1918) and Wilson Grade No. 9 (Patented U. S. A., June 13, 1916; March 9, 1920) were used.

And there is a grade (analysis) that will exactly meet your own particular welding needs. Each grade of Wilson Wire runs uniform throughout—every rod is just like every other rod in the grade you select.

Perhaps you are confronted with a welding problem that Wilson has already solved successfully for others. Why not write today for a sample? Just indicate the kind of metal you desire to weld. Also, ask for bulletins describing Wilson Welding Machines.

WILSON WELDER & METALS CO. INC., WILSON BLDG., HOBOKEN, NEW JERSEY

WILSON

WELDING MACHINES AND WELDING WIRE

SWEDOX

WELDING RODS, WIRES and ELECTRODES

A Grade for Every Purpose

NONOX SWEDOX
LEKTROX SWEDOX
CASTOX
ARC CARBOX
GAS CARBOX
VANOX

TENSKOTE
DUCTKOTE
DUCTILOX
NICKOX
RAILOX

BRONZOX
BRONZKOTE
TOBIN BRONZE
MANGANESE BRONZE
MONEL METAL

STEELKOTE
LEKKOTE
CYLKOTE
MANKOTE
RAILKOTE

KROMOX
MANGANOX
ALUMINOX
DRAWN ALUMINUM
BRAZOX

TENSILOX
KROMKOTE
NICKOTE
VANKOTE
FLUXES

SEND FOR TESTING SAMPLE

We want every welder in the country—big or small—to be convinced of the *specialized superiorities* of SWEDOX products. We know that a trial *will* convince you. Hence the free offer. Try SWEDOX on your next welding job at our expense.

CHICAGO, ILL.
4545 S. Western Blvd.
Phone:
LaFayette 8500

Central Steel & Wire Company

DETROIT, MICH.
5001 Bellevue Ave.
Phone:
Lincoln 6780

"We Ship the Same Day"

WE ANNOUNCE

That on and after February 21st, 1927, our Offices, Factory and Service Department will be

MOVED

to LARGER QUARTERS without interrupting sales or service

AT

515 West 29th St., New York City

Phone number will be the same Chickering 0996-7-8

K-G WELDING & CUTTING CO., Inc.

Before you settle on the type of machine— get the users viewpoint

Any Lincoln office below will put you in touch with a user near you whose experience covers many types of welders. Get his viewpoint based on experience.

They say

(a new list in each issue)

"The machine has more than paid for itself since we have had it in use (6 months)."

* * *

"We assure you that the welders are giving us excellent service and are used extensively in our plant."

* * *

"A wonderful saving has been effected through the use of this machine."

* * *

"I am perfectly satisfied with my Lincoln welder."

* * *

"It gives us much pleasure and satisfaction to inform you that we have never lost a weld made with this machine."

LINCOLN "Stable Arc" WELDER

Branch Offices
Baltimore
Boston
Buffalo
Charlotte, N. C.
Chicago
Cincinnati
Detroit
Des Moines
Grand Rapids

The Lincoln Electric Co.

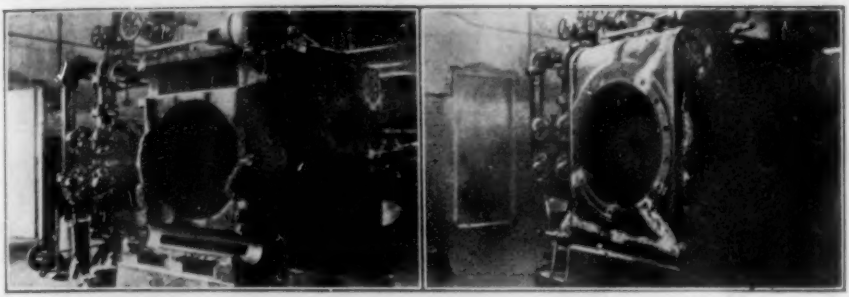
General Offices and Factory:
Cleveland, Ohio

The Lincoln Electric Co. of Canada, Ltd., Toronto-Montreal

Branch Offices
Indianapolis
Milwaukee
Minneapolis
New York City
Philadelphia
Pittsburgh
Rochester
St. Louis

Distributing agencies in all principal cities

Exclusive Agencies with Stock:
Ft. Worth, Texas
New Orleans
Los Angeles
San Francisco



How a badly broken Corliss engine cylinder was repaired quickly and permanently

THE entire head end of a high pressure cylinder was broken off on a line through the center of the steam-valve chamber, the cylinder proper and the exhaust valve chamber.

Five welders worked in shifts, using the oxy-acetylene process and Tobin Bronze Welding Rods. The actual welding time was 21 hours, with a total of 63 man-hours.

The materials required were 216 pounds of ¼-inch Tobin Bronze Welding Rods; 5½ pounds of welding flux; 1270 cubic feet of acetylene, and 1339 cubic feet of oxygen.

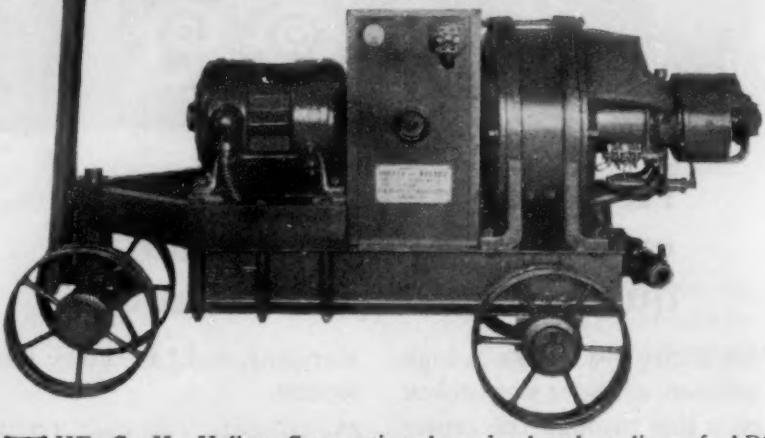
Ordinarily, the use of Tobin Bronze eliminates the need of extensive preheating. In this case the masses of metal were so great that a preliminary heating was considered necessary.

After all work was done, a cold water test of 170 pounds per square inch gave no sign of a leak and the engine was put back into service. A new cylinder would have cost $1200. The total cost of the repair job with Tobin Bronze was one-half that amount.

THE AMERICAN BRASS COMPANY
GENERAL OFFICES: WATERBURY, CONNECTICUT
Canadian Mill: Anaconda American Brass Ltd., New Toronto, Ont.

TOBIN BRONZE
REGISTERED U.S. PATENT OFFICE
WELDING RODS

The HOLLUP ARC WELDER



THE C. H. Hollup Corporation has developed a line of ARC WELDERS in which are incorporated all the practical ideas gained during ten years of specializing in electric arc welding. The "HOLLUP ARC WELDER" comprises a specially designed arc welding generator coupled to a standard motor or gas engine, with control panel mounted on a welded structural steel base.

Hollup Arc Welders are furnished in capacities of 200 or 300 amperes, motor or gas engine drive. Stock delivery.

Exclusive, practical features of the HOLLUP ARC WELDER are:

Simplicity

Automatic start and stop control.
Single heat control.

Safety

Welding leads may be disconnected or reversed without touching or exposing any current carrying parts.
No exposed switches or current carrying parts.
Control panel constructed of steel,—eliminating the use of fragile switch board material.
Automatic no-voltage and overload protection.

Convenience

Exceptionally compact design—all controls at one point.
Plug and receptacle especially designed for quickly disconnecting both welding leads and also for reversing polarity, which is self indicating.
All bases drilled so that a standard running gear (truck) may be quickly attached at any time.
Low center of gravity and short turning radius of portable machines.
Generator and motor are entirely unobstructed for inspection and maintenance.

Reliabilty

Generator, truck and base designed and built for arc welding requirements.
Ball bearings are used throughout the electrical units, and roller bearings are used on all trucks.
Use of flexible coupling gives independent alignment and balance to both generator and motor. This coupling also permits the use of a standard motor which is easily interchangeable.

Welding Characteristics

The welding characteristics of the Hollup Arc Welder are best described by the word "work-wise"—the product of the combined ideas of several of the foremost welding engineers in the United States. The maximum amount of metal can be deposited efficiently for any given class of work, with the least amount of effort on the part of the operator.

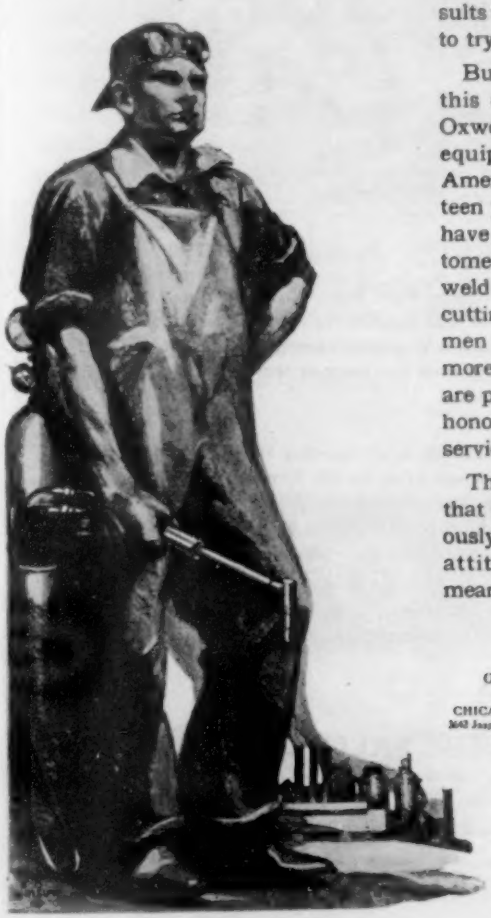
C. H. Hollup Corporation
3333 West 48th Place
Chicago, Ill.

Manufacturers of the well known
"Wanamaker Coated Electrodes"
"Rex Processed Electrodes"
"Rex Oxy-Acetylene Welding Rods"
"Rex Accessories"

We are interested in handling the Hollup Arc Welder in the territory noted below and would like you to submit your proposition to us.

Name .....
Address .....
City .....
Territory wanted .....

There are two kinds of "service"



ONE KIND of "service" means only promises and the other kind produces results.

We do not ask you to believe that Oxweld service means results until you have had occasion to try it.

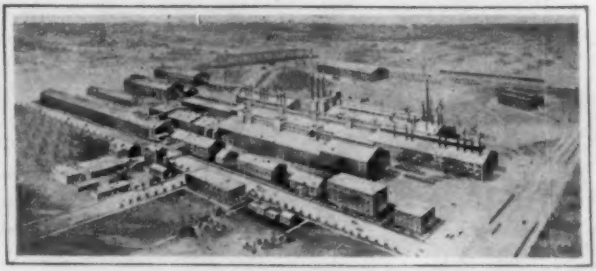
But we do ask you to think this over! For fourteen years Oxweld injector blowpipes and equipment have been sold to American industries. For fourteen years Oxweld service men have aided and instructed customers in the efficient use of Oxweld equipment for welding and cutting. Some of these service men have been with Oxweld for more than ten years. And they are proud of the job, for it is an honor to be selected for Oxweld service work.

These are facts. They indicate that Oxweld takes service seriously and believes in it. It is an attitude toward service that means—results.

OXWELD ACETYLENE COMPANY
Unit of Union Carbide and Carbon Corporation
CHICAGO 3642 Jasper Pl. UCC SAN FRANCISCO 1000 Mission St.
LONG ISLAND CITY, N. Y. Thompson Ave. and Orton St.
STOCKS IN 39 CITIES

Oxweld
WELDING AND CUTTING APPARATUS

One factory
vs.
100,000 people



IN the plant of the Niagara Falls Power Company there is a great electric generator that supplies the city of Syracuse with light and power. Beside it is another exactly as large, yet it is not large enough to supply even one plant of the Union Carbide Company with electric current.

The story of Union Carbide is an amazing story of growth. Back of it lies the development of an electric furnace process that gives a uniform high quality product. Without Union Carbide many new industrial practices could not have been developed and much new equipment could not have been produced.

Quality and uniformity of product lie at the foundation of this achievement as they do in all substantial industrial successes.

UNION CARBIDE SALES COMPANY

Unit of Union Carbide and Carbon Corporation

UCC

Carbide and Carbon Building, 30 East 42d Street, New York

Peoples Gas Building, Chicago, Ill. *Adam Grant Building*, San Francisco, Cal.

UNION CARBIDE WAREHOUSES IN 180 CITIES

Are you suspicious of flame-cut steel? ★

THE REAL ECONOMY of cutting steel with the oxy-acetylene flame is well established. A three pound blowpipe replaces massive machinery. Even in shops that have installed such machinery the odd jobs and emergency jobs are more quickly accomplished by the oxy-acetylene process. It eliminates the delay of routing heavy pieces back to the shears.

Nevertheless there is a groundless suspicion that the heat of the flame has damaged the steel. Some engineers even insist on machining ⅛" to 1" of metal from the flame-cut edges.

Now it is a fact established by several different engineering investigations that mild steel and structural steel are actually stronger after they have been flame cut. Bars taken from the flame-cut edge show a bending strength of 5%-10% higher than those from a milled edge. A slight hardening takes place ⅛" to 5/16" inward from the surface.

Linde Engineers can supply you with convincing metallurgical data on the various applications of the oxy-acetylene process.

THE LINDE AIR PRODUCTS COMPANY
Unit of Union Carbide and Carbon Corporation
General Offices: Carbide and Carbon Building
30 East 42d Street, New York
37 PLANTS . . . . . 107 WAREHOUSES

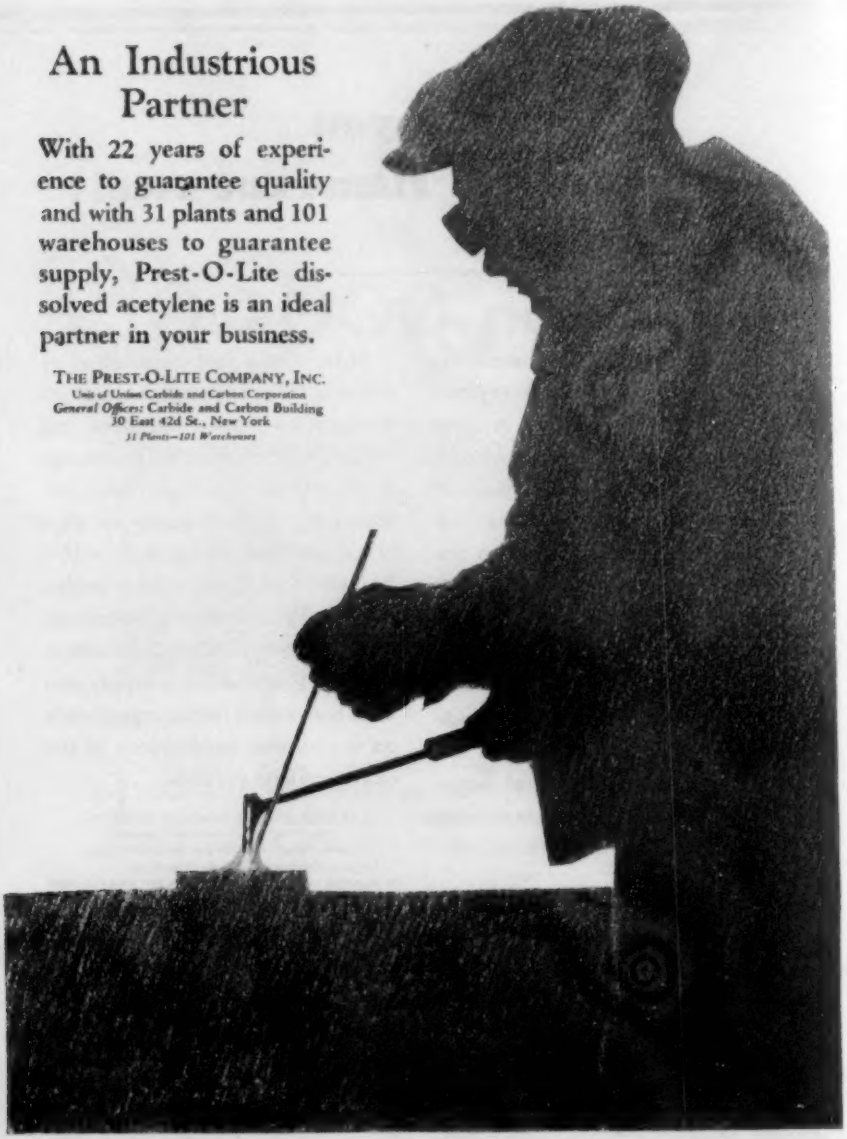
LINDE OXYGEN

★ No. 6 of a series of advertisements on the engineering phases of oxy-acetylene welding and cutting. Send for the booklet entitled "Engineering and Management Phases of Oxwelded Construction."

An Industrious Partner

With 22 years of experience to guarantee quality and with 31 plants and 101 warehouses to guarantee supply, Prest-O-Lite dissolved acetylene is an ideal partner in your business.

THE PREST-O-LITE COMPANY, INC.
Unit of Union Carbide and Carbon Corporation
General Offices: Carbide and Carbon Building
30 East 42d St., New York
31 Plants—101 Warehouses



Prest-O-Lite
DISSOLVED ACETYLENE

Roebling Welding Wire

ROEBLING Welding Wire makes strong, tough welds, is positively uniform throughout all shipments and conforms to all standard specifications.

John A. Roebling's Sons Company
Trenton, New Jersey

It's Arc Welded!

Above, 70 ft. by 120 ft. standard mill-type building completely arc welded by the Youngstown Welding Company

Insert. View of the welded joints—the strongest link in the chain

7 men did it—in 15 days. They used two arc welders, a burning outfit, a welded derrick, and a tractor. Not one rivet or bolt was used in fabrication or erection.

Total cost of fabrication and erection..... .....$530
Estimate for similar riveted job (*erection only*)...$540

Fabrication by arc welding means these practical advantages:

- Engineering work greatly simplified
- Elaborate auxiliary drawings eliminated
- Structural shop eliminated—all work done in the field
- Handling charges reduced—materials shipped directly from mill to job
- Large saving in materials
- Flexibility—changes in design during construction easily made with no waste of materials
- Field equipment simple and inexpensive—total for above job, $3000

This is just a beginning. Experience will bring greater simplification, greater speed, greater economies. Your nearest G-E office will be glad to give you the complete details of this job and much valuable information as to the G-E welder best suited to the fabrication of structural steel. Write or phone.

General Electric furnishes to the Welding Industry:

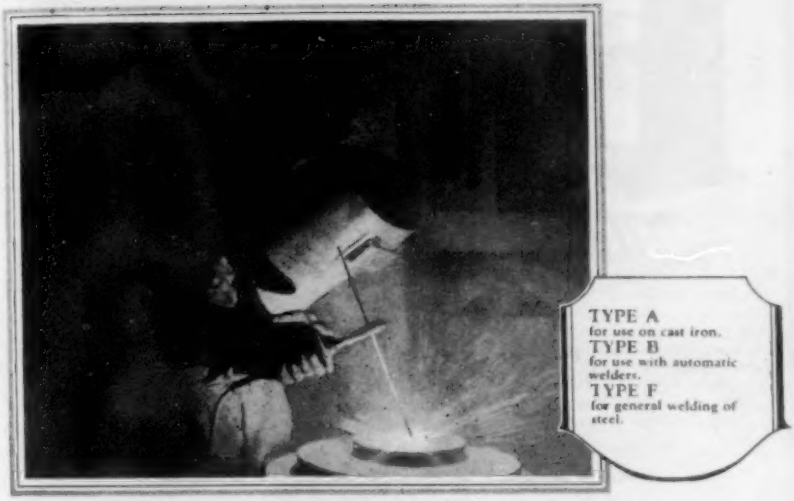
- WD Arc Welders—designed for one operator
- Constant Potential Sets—for several operators
- Arc Welding Resistors—for mining and traction companies
- Automatic Sets—for repetition work

Complete information and bulletins available at your nearest G-E office.

530-27D

GENERAL ELECTRIC

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., SALES OFFICES IN PRINCIPAL CITIES



The Difference is in the Treatment

Ordinary welding wire has minute pores filled with moisture and hydrogen which cause tiny explosions—sputtering—dissipation of the metal.

The base wire of Type "F", G-E Welding Electrode alone is a good bare electrode. By a special General Electric process, moisture and hydrogen are reduced to an absolute minimum. Stabilizing substances become a part of the electrode.

The arc is much more stable. It is more concentrated.

Naturally, an operator working with Type "F", G-E Welding Electrode can produce better work and more of it. Doesn't this suggest real economy? Any of the special G-E Welding Electrode Distributors will be glad to give you more information and samples.

In absolute reliability of operation and overall efficiency, there is no superior to G-E Arc Welders. They are available in all sizes, all types—for either hand or automatic operation—for single or multiple operator.

Special Distributors for G-E Welding Electrodes

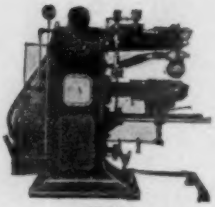
American Steel Eng. Co., 10 South 18th St., Philadelphia, Pa. also 601 Granite Bldg., Pittsburg, Pa.
Bird-Potts Co., Atlanta, Ga.
Capital Electric Co., Salt Lake City, Utah.
Robert M. Hartwell, 153 East 2nd St., Los Angeles, Cal.
Industrial Sup. Co., Inc., 329 East Second St., Los Angeles, Cal.
Hendrie & Bolthoff Mfg. & Supply Co., Denver, Colo.
P. F. McDonald & Co., 17 King Terminal, Boston, 27, Mass.
Matthews Electric Sup. Co., 1823 First Ave., Birmingham, Ala.
National Welding Equip. Co., 223 Main Street, San Francisco, Cal.
Root, Neal & Co., Buffalo, N. Y.
Joseph T. Ryerson & Son, Inc., Chicago, Ill. also Cincinnati, O. Detroit, Mich. St. Louis, Mo.
Seattle Hardware Co. Seattle, Wash.
Southern Electric Co., Baltimore, Md. also Charlotte, N. C. Norfolk, Va. Richmond, Va.
Southwest General Elec. Co., Dallas, Texas. also Houston, Texas. Oklahoma City, Okla.
Strong, Carlisle & Hammond Co., Cleveland, Ohio.
Union Iron Works, Spokane, Wash.
Virginian Electric Inc., Charleston, W. Va.
A. J. Wilson Co., Inc., 130 Liberty St., New York, N. Y.
W. A. Ramsey, Ltd., 74 Queen St., Honolulu, Hawaii.
Oliver H. Von Horn Co., Inc., 522-534 Camp Street, New Orleans, La.
Welding Service Co., 50 Church Street, New York, N. Y.

550-15D

GENERAL ELECTRIC

MERCHANDISE DEPARTMENT, BRIDGEPORT, CONNECTICUT

SPOT



SEAM

ARC

For Production
Electric Welding
Machines

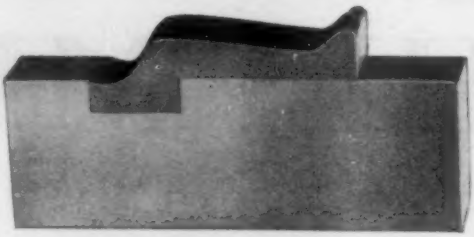
Gibb Welding Machines Company

Bay City, Michigan

New York—Philadelphia—Cleveland—Cincinnati—Detroit—Buffalo
Chicago—St. Louis—Los Angeles—Toronto—Montreal

BOUND VOLUMES JOURNAL NOW READY

A number of Bound Volumes of the Journal for 1926 have been bound in attractive book form. Members may obtain copies at $5.00, non-members $10.00.



THIS WELDING JAW

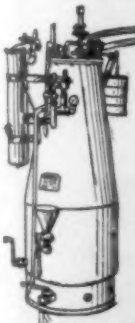
ELKONITE
resistance welding
ELECTRODES
stand up
where copper
FAILS.

Is being used by one of the largest automobile wheel manufacturers for flash welding automobile rims, because of the great saving it affords over all other materials in productivity, material, time and shrinkage. Elkonite is proving to be the answer to many important problems in resistance welding operations—flash, projection, spot welding, especially aluminum and brass, cross-wire, electrical upsetting of rivets, etc.

Descriptive data on request.

ELKON WORKS, INC.
WEEHAWKEN, N. J.

Exclusive licensees under General Electric Co. patents dated May 28, 1925 and September 1, 1925. Other patents pending to Elkon Works.



Why Experiment?

Torches
Regulators
Generators
Compressors
Manifolds
Preheaters
Paint Sprays
Carbide Lights

Catalog 547

SINCE the infancy of the industry, expert engineers and skilled workmen have maintained the predominance of Milburn Equipment.

Its acceptance as standard equipment by large industrials, railroads and Government Departments the world over exemplifies Milburn leadership.

THE ALEXANDER MILBURN CO.
Baltimore, Md.

Every welding operator interested in Better Welding will find Bulletin No. 119—"Coated Rods for Metal Arc Welding" —of real value. Ask for a copy.

UNA WELDING AND BONDING COMPANY

1615 Collamer Ave., Cleveland, Ohio

Welding Processes
Welding Rods

UNA

A.C.-D.C. Welders
Welding Supplies

THERMIT

1902 1927

Twenty-five years ago the Thermit process of welding was introduced into this country from Europe. During the intervening time its use has increased rapidly, until today it is universally recognized as the most practical means of repairing medium and heavy size sections of iron and steel.

Our engineering organization is continually carrying on experimental work in an effort to produce better methods, better materials and better equipment. A well-known instance of the success of such research is the present practice of Thermit welding which reduces the cost 50 per cent over the former methods.

The Thermit welding process is scientifically correct, inexpensive, proven, practical and simple in its application to all classes of work—the weld is permanent and the welded part is of the same or of greater strength than the original.

WELDING

METAL & THERMIT CORPORATION

120 Broadway, New York City

Chicago Pittsburgh Boston 5 San Francisco Toronto

THERMIT WELDING

Instructions for the making of
Thermit Welds

Compiled by the Educational Committee of the American Welding Society as a source of reference for welders or operators using the Thermit Process.

JUNE, 1927

Published by the
AMERICAN WELDING SOCIETY
33 West 39th Street,
New York, N. Y.

Copyright 1927
by
American Welding Society

THERMIT WELDING

Instructions for the Making of Thermit Welds

TABLE OF CONTENTS

	Page
Editor's Preface	4
Kinds of Thermit	5
Making a Thermit Weld	5
Welding Locomotive Frames	8
Crankshaft Repairs	24
Steel Mill Repairs	26
Welding Rails	34
Marine Repairs	48
Welding Pipe With Thermit	49

EDITOR'S PREFACE

The three most important characteristics of a successful training program are: (1) a selected group of learners, (2) an occupationally competent instructor who has been trained in the art of teaching, and (3) functioning subject matter.

The American Welding Society has been engaged for a number of years in an attempt to promote the art of fusion welding through an adequate supply of competent welders. Several years ago it published in bulletin form an analysis of training courses for oxy-acetylene welders and for electric arc welders. These courses were prepared by representative committees, the members of which gave freely of their time and effort to the completion of these reports. These reports are known as Bulletin No. 4, Training Course for Oxy-Acetylene Welders, and Bulletin No. 7, Training Course for Electric Arc Welders.

More recently additional committees were created under the leadership of Mr. E. H. Ewertz as chairman, for the purpose of preparing manuscripts on the fundamentals of welding and formulating the work of both committees into a manuscript which will serve as an authentic and up-to-date text for the training of welders.

The work of Mr. Ewertz' committees was divided into four parts as follows:

Training Oxy-Acetylene Welders.
Training Electric Arc Welders.
Training Resistance Welders.
Training Thermit Welders.

Each of these reports was prepared by a special committee, the membership of which represented the late and most successful practices in that particular phase of welding. This part deals with THERMIT WELDING.

The American Welding Society is especially indebted to Mr. F. E. Rogers of the Air Reduction Sales Company, and to Mr. L. E. Ogden of the Oxweld Acetylene Company, for the manuscript on oxy-acetylene welding; to Mr. C. J. Holslag of the Electric Arc Cutting & Welding Company, and Mr. W. L. Warner of the General Electric Company, for the part dealing with electric arc welding; to Mr. H. A. Woofter of the Swift Electric Welding Company for the part on resistance welding; and to Mr. W. R. Hulbert of the Metal and Thermit Corporation for the part on thermit welding.

Executive Committee

E. H. Ewertz, Consulting Engineer, 50 Church St., N. Y.
J. C. Wright, Federal Board for Vocational Education, Washington, D. C.
F. E. Rogers, Air Reduction Sales Company, 342 Madison Avenue, New York, N. Y.
C. J. Holslag, Electric Arc Cutting & Welding Company, 152 Jelliff Ave., Newark, N. J.
W. L. Warner, General Electric Company, Schenectady, N. Y.
L. E. Ogden, Oxweld Acetylene Company, 30 East 42nd Street, New York, N. Y.

The manuscript presents the best knowledge available, not only from the welding standpoint but also from the standpoint of experience in preparing subject matter for training courses. All welding schools, both public and private, are urged to give it the most careful consideration and to use it as a text and guide in laying out proper courses for the training of welders. The arrangement of the subject matter is flexible and can be easily adapted to programs organized for the purpose of preparing new workers to enter this industry, as well as for the purpose of extending the technical education and skill of those already employed as welders.

J. C. WRIGHT,
Editor.

Thermit Welding

Instructions for Making Thermit Welds

Thermit is a trade name for a mixture of finely divided aluminum and iron oxide, which when ignited reacts to produce a superheated liquid steel at 5000 deg. Fahr.

The underlying principle of the thermit process is the high chemical affinity of aluminum for oxygen. Up to a temperature of 2800 deg. Fahr., thermit is an inert mixture. At that temperature, however, the aluminum unites with the oxygen of the iron oxide, and the iron is set free and comes down as a highly superheated liquid steel at a temperature of approximately 5000 deg Fahr., or about twice the temperature of ordinary molten steel. It is obvious that if steel at this temperature is poured around the sections to be united, especially if the sections have previously been preheated to a bright red heat, it will melt those sections and amalgamate with them so that the whole will cool to form a single homogeneous mass, or in other words a fusion weld.

Kinds of Thermit for Welding.—At the present time there are four varieties of thermit produced for the purpose of welding ferrous material, i.e., Plain thermit, Cast iron thermit, Railroad thermit, Wabbler thermit.

Plain thermit is a mixture of finely divided aluminum and iron oxide and is used in making pipe welds where the thermit is merely used as a heating agent to bring the pipe ends up to a welding temperature.

Railroad thermit is plain thermit with a 17 per cent addition of nickel, manganese and mild steel punchings. This grade of thermit is used in connection with all steel welds.

Cast iron thermit is plain thermit with an addition of 3 per cent ferro silicon and 20 per cent mild steel punchings and is used for welding cast iron parts together.

Wabbler thermit is designed to produce a hard, long wearing, yet machinable steel for building up worn wabbler ends of rolls and pinions.

Making a Thermit Weld.—In making a thermit weld, the parts to be united are first lined up with a space between the ends to be welded, the extent of which depends upon the size of the sections to be welded. The adjacent ends are then thoroughly cleaned by a sand blast or other suitable means.

A wax pattern is then formed around the ends to be united of the exact shape of the reinforcement of thermit steel which is to be cast at that point to make the weld.

A sand mold is next rammed around the wax pattern and inside a sheet iron box, provision being made in the mold for the necessary number of pouring gates, heating gates and risers (depending on size of weld), the risers communicating with the highest points

of the wax pattern and the heating and pouring gates with the lowest point.

Fig. 1 shows a longitudinal and cross section of a typical mold. The function of the vent holes is primarily to vent and dry out the interior of the mold in accordance with good foundry practice. The basin shown on the top of the mold serves simply as a safeguard for the purpose of catching the slag when the pour is made and for the purpose of preventing it from spilling over.

The flame of a compressed air liquid fuel (gasoline or kerosene) heater, Fig. 2, directed into the heating gate melts the wax pattern and leaves a space between and around the ends to be welded to be later occupied by the thermit steel. The heat is continued until

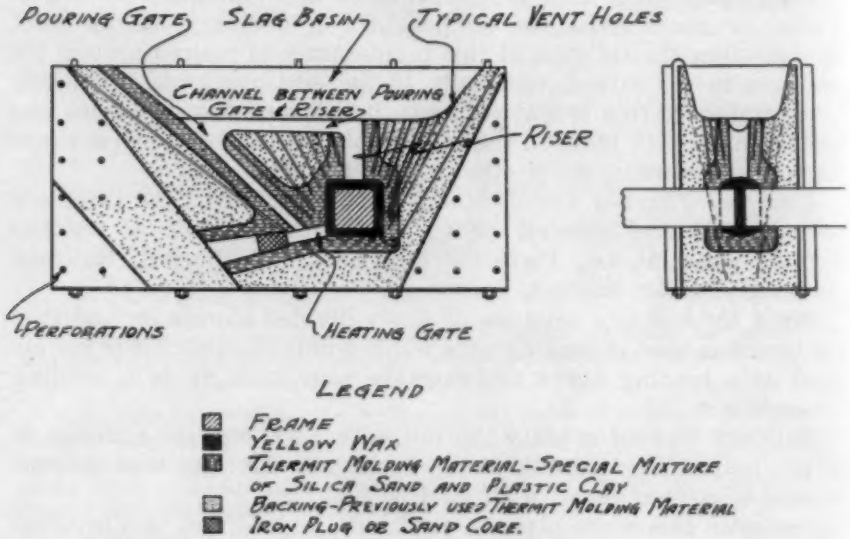


Fig. 1. Method to be employed in constructing molds for making thermit welds and materials needed.

the parts to be united have been brought to a good, red, workable heat. By that time the mold will have become dried out. In the meantime the charge of thermit is placed in a conical shaped crucible supported over the pouring gate of the mold. When the sections are red hot and the mold dried the application of heat is discontinued, the heating gate plugged up and the thermit charge in the crucible ignited. In from 25 to 35 seconds the thermit reaction is completed and the thermit steel tapped from the bottom of the crucible into the mold in bulk where it flows around and between the sections to be welded, uniting them into one homogeneous mass. Fig. 3 shows the cross section of the crucible plugged ready to receive the thermit. Tapping the crucible consists of pushing the tapping pin up into the crucible by means of a tapping spade, which is simply a bar of pipe of convenient length flattened for a few inches in the end to engage the tapping pin.

The initial temperature of 2800 deg. Fahr., required to start the thermit reaction, is obtained through the medium of an ignition powder, which is in turn ignited by means of a match or red hot iron rod.

The slag (aluminum oxide) does not enter the mold, but overflows into the mold basin, so that it does not interfere with the welding operation. The amount of thermit required for a given weld is readily determined from the weight of wax in the pattern. Each pound of wax in the pattern calls for 20 lb. of the railroad thermit mixture.

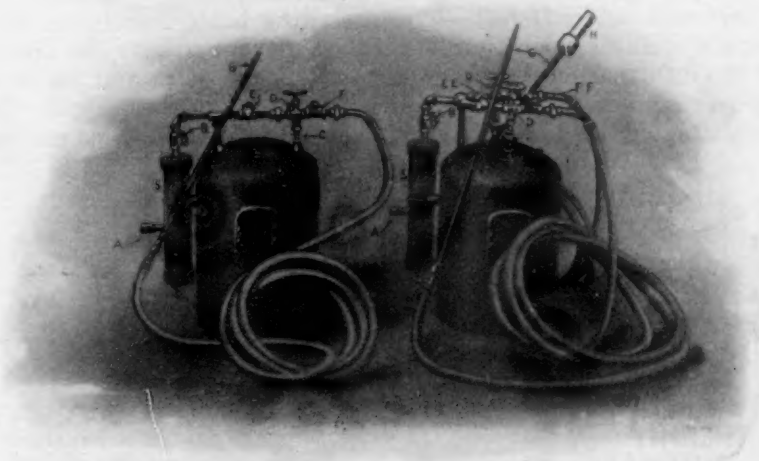


Fig. 2. Single burner and double burner preheater, showing water separators and flaming burner attachment. These preheaters operate on either gasoline or kerosene.

A—Attach hose from compressed air supply.
B—Admits air to preheater.
C—Tube running to within a few inches of the bottom.
D—Needle valve—controls fuel to burner.
E—Valve to control pressure of air to burner.
F—Check valve—prevents backfire.
G—Torches or burner pipes.
H—Flaming burner attachment.
S—Water separator.

It will be seen that the process is a simple one and that the only outside power required is a supply of compressed air for the operation of the preheater. The outfit is entirely portable and in many cases sections of very large size are welded without the necessity of removing them from their position, and therefore at a great saving in time and expense over obtaining new parts or repairing by other means. This is particularly advantageous in the case of locomotive repairs. It saves taking the frame out of the engine, welding it in a forge and replacing it. Furthermore, the process permits of fusing a collar or reinforcement of steel all around the welded part, thus increasing the cross section at that point and making it stronger than it was originally.

Fig. 2 shows a thermit single and double burner preheater especially designed to burn a mixture of air and liquid fuel (either gasoline or kerosene) in such a manner that the combustion takes

place in the interior of the mold where it is required to heat the parts to be welded.

FIELDS OF APPLICATION IN WHICH THE THERMIT PROCESS OF WELDING IS BEING EMPLOYED EXTENSIVELY AT THE PRESENT TIME

Locomotive repairs	Steel mill repairs
Marine repairs	Pipe welding
Crankshaft repairs	Rail welding

Miscellaneous heavy welding

Instructions In Detail.—The preceding brief description of the thermit welding operation is hardly sufficient to give the operator all the information necessary to carry on the work and the following pages, therefore, take up the subject in greater detail. However, it should be borne in mind that most thermit welds are made

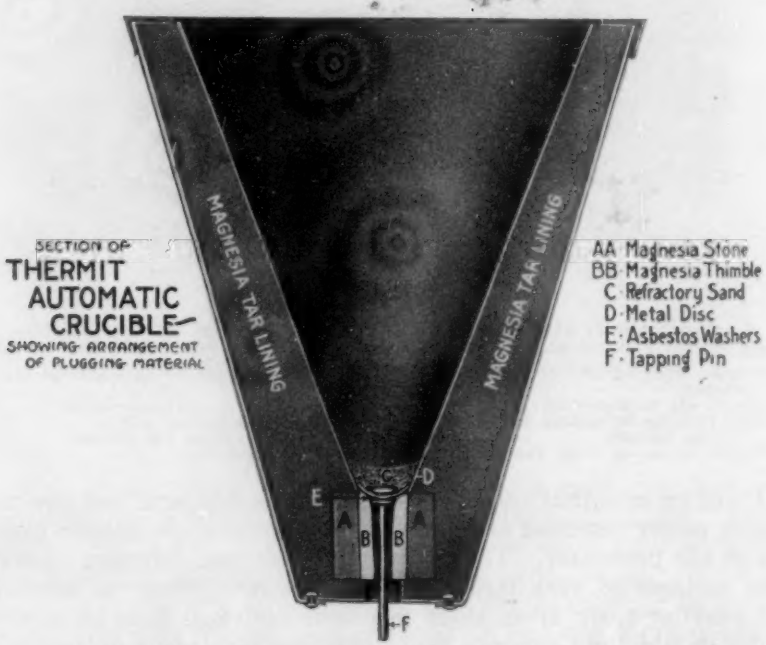


Fig. 3. Section of thermit automatic crucible showing arrangement of plugging material.

in substantially the same way, whether it be a weld of a broken locomotive frame, crankshaft or the stern frame of a steamship; the same points must be observed and followed. We will therefore follow through the welding of a locomotive frame as a typical welding operation and later on, in describing other operations, only take up the special features which cause the operation to differ from the typical case.

WELDING FRAME

Welding a Locomotive Frame—General Directions.—1. After having removed such parts of the engine necessary to make the fracture accessible and allowing room for the mold box 15 in. wide, set screw jacks to support the frame so that neither section can

TABLE 1—THERMIT WELD DIMENSIONS AND PORTIONS REQUIRED FOR ROUND SECTIONS*

Dia. Inches	Gap Inches	Collar Inches	Riser Dia. Inches	No. Pouring Gates Dia. Inches	No. of Heating and Connecting Gates and Dia. Inches	Thermit Required Pounds	Dia. Inches
2	1/8	1¼x 1/8	¾	1—1	1 1	6	2
3	1/8	1⅝x 1/8	1	1—1	1 1	9	3
4	⅛	2¼x ⅛	1	1—1	1 1	13	4
5	⅜	2⅝x ⅜	1½	1—1	1 1	24	5
6	1/4	3¼x 1/4	1½	1—1	1 1¼	35	6
7	1/4	3½x 1/4	1½	1—1	1 1¼	50	7
8	⅜	4 x ⅜	2	1—1	1 1¼	65	8
9	1	4⅝x1	2	1—1	1 1¼	90	9
10	1 1/8	4⅞x1 1/8	2	1—1¼	1 1¼	115	10
11	1⅛	5¼x1⅛	2½	1—1¼	1 1¼	150	11
12	1⅛	5⅝x1⅛	2½	1—1¼	2 1¼C	185	12
13	1¼	6 x1¼	2½	1—1¼	2 1¼C	225	13
14	1⅛	6⅜x1⅛	2½	1—1¼	2 1¼C	260	14
15	1⅜	6¾x1⅜	3	1—1½	2-1¼C & 1-1¼NC	335	15
16	1½	7⅛x1½	3	1—1½	2-1¼C & 1-1¼NC	375	16
18	1⅛	7⅞x1⅛	3	1—1½	2-1½C & 1-1½NC	500	18
20	1 1/4	8⅝x1 1/4	3	2—1¼	4 1½C	650	20
22	1 1/4	9⅛x1 1/4	3½	2—1¼	4 1½C	825	22
24	1 1/4	10¼x1 1/4	3½	2—1½	4 1½C	1100	24
26	2	11 x2	3½	2—1½	4 1½C	1300	26
28	2⅛	11⅝x2⅛	4	2—1½	6 1½C	1525	28
30	2¼	12⅛x2¼	4	2—1½	6 1½C	1800	30

Note—"C" indicates gates connected to pouring gate. "NC" indicates gates not connected to pouring gate.

Diameters shown above for pouring gates are mean diameters. In practice these pouring gates should be tapered, bottom diameter approximately ⅛ in. less and top diameter approximately ⅛ in. greater than dimensions given.

*Table of recommended thermit weld dimensions and portions in accordance with the United States Patent No. 1549461, dated August 11, 1925, and entitled, "Method of Welding Metals." Users of Thermit are licensed to operate under this patent by the Metal & Thermit Corporation. Copyright, 1926, by Metal & Thermit Corporation.

sag. Then place tram marks on the frame far enough apart to come outside of the mold box so as to gauge allowance to be made for contraction. Then cut out the metal along the line of the fracture so that an opening as shown in Table I is provided. There

are two ways of doing this, the latest and quickest method being to employ a cutting flame of gas and oxygen. If this method is not available, a series of holes should be drilled along the line of the break and afterward all metal between the holes should be removed so as to make a clean opening for the free flow of thermit steel between the sections to be welded together. If the fracture runs diagonally, in the case of a horizontal member, it is advisable, when cutting out, to make the opening as nearly vertical as possible.

2. Clean the frame thoroughly so as to expose two inches, or so, of good bright metal on each side of the fracture and be sure to remove all dirt and grease as far back as the mold box will reach,

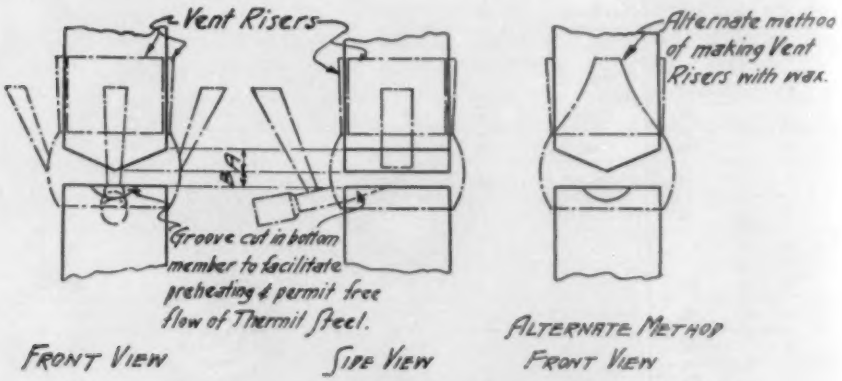

Vent Risers
Groove cut in bottom member to facilitate preheating & permit free flow of Thermit Steel.
Alternate method of making Vent Risers with wax.
FRONT VIEW
SIDE VIEW
ALTERNATE METHOD
FRONT VIEW

Fig. 4. Method to be employed in welding locomotive frame broken in leg.
Dimension A equals twice the gap given in Table I.
Dimension B equals half the gap given in Table I.
For dimensions of heating and pouring gates see Table I.
Risers for vertical welds should be rectangular, long dimension to be the same as diameter given in table on previous page, short dimension to be one-half of it.
Vent risers (wooden boards slightly tapered) should be about ¼ in. thick and placed on all sides of section.
In making vertical welds the gate should be located as shown, in order that thermit steel should enter mold under apex of the "V."

so that when the mold is rammed and the heat applied there will be no grease to burn out and leave a space between the mold and the frame. The best method of cleaning is, of course, the sand blast, but careful thorough cleaning with a wire brush will be satisfactory. If oxy-acetylene is used for cutting, be sure to remove all oxide and scale left on the frame from the cutting operation.

3. Care should be taken to see that the frame is in perfect alignment, after which it should be expanded according to the location of the break and section. If the fracture occurs between jaws, force the frame apart by means of a screw jack or other spreading means (such as the end of an old main rod cut off to fit the parts to be spread, as shown in Fig. 5) so as to open the gap and force the frame apart 3/16 in. to 5/16 in., depending upon the size of the frame and the length of the time of preheat. It is evident that this allowance is closely dependent upon the length of time of preheating because, the longer the time, the more the heat soaks back

into the frame and the more the original gap allowed will be reduced. In other words, the longer the preheat, the greater the allowance for contraction. A little careful observation on the first few welds made will soon make the operator expert in judging this allowance.

If the expansion cannot be taken care of with a jack or other mechanical means, it will be necessary to heat a parallel member by means of the flaming burner attachment on a double burner

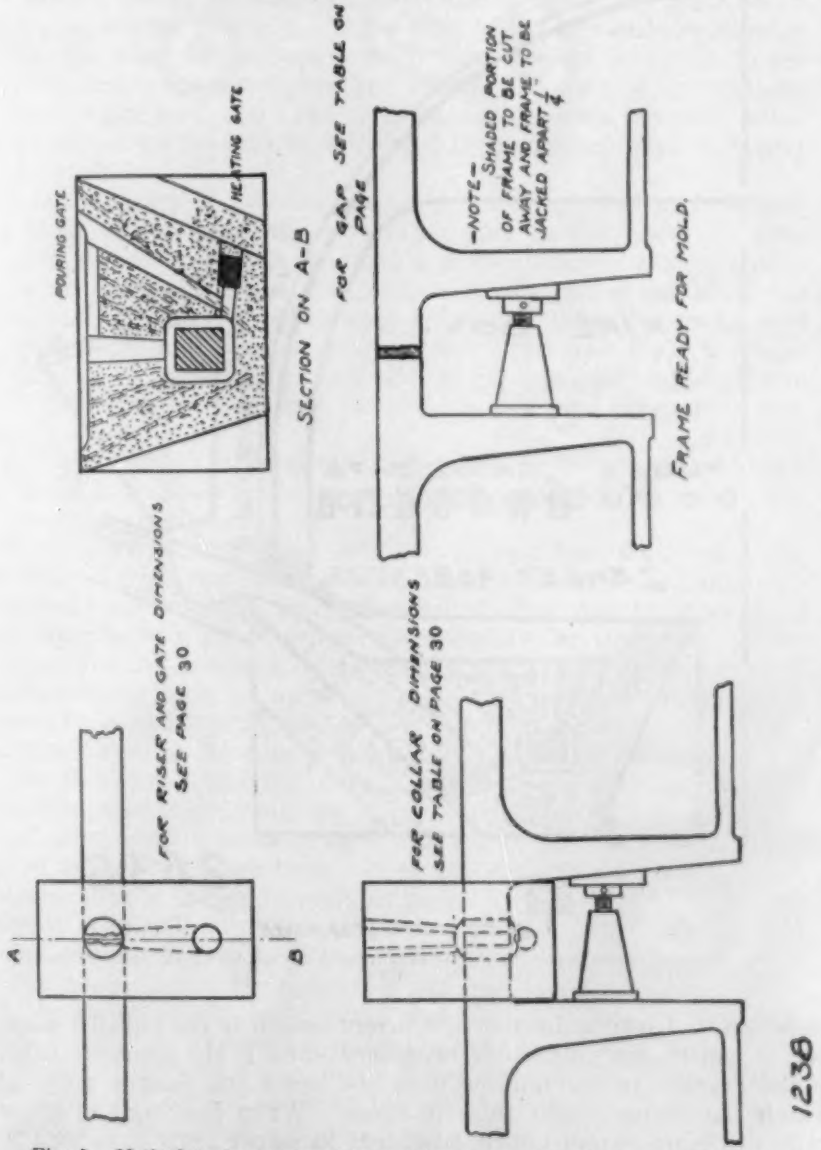

POURING GATE
HEATING GATE
SECTION ON A-B
FOR GAP SEE TABLE ON PAGE
-NOTE- SHADED PORTION OF FRAME TO BE CUT AWAY AND FRAME TO BE JACKED APART 1/4"
FRAME READY FOR MOLD.
FOR RISER AND GATE DIMENSIONS SEE PAGE 30
FOR COLLAR DIMENSIONS SEE TABLE ON PAGE 30
A
B
1238

Fig. 5. Method to be employed in welding locomotive frame broken in jaw.

preheater or by a basket fire. If possible, considerably more of the parallel member should be heated than is included in the mold box of the member being welded, in order to gain sufficient expansion by this method. This heating should be done while the fracture is being preheated, but care should be taken not to heat too hot, as the frame is likely to upset. A black heat is usually

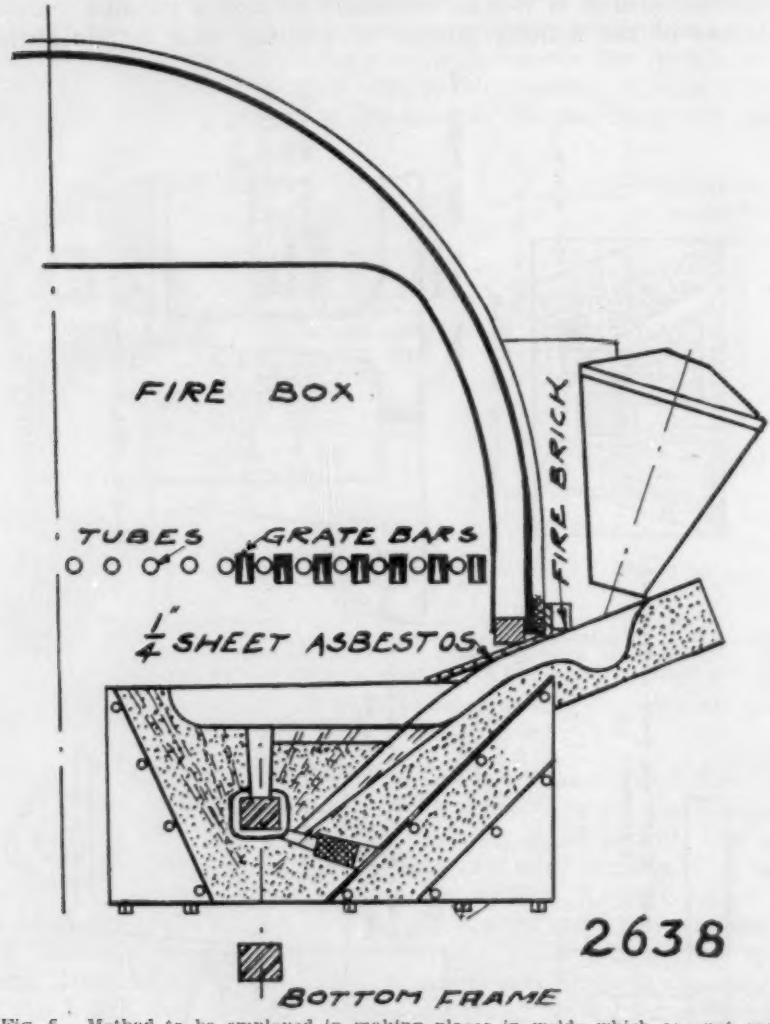


Fig. 6. Method to be employed in making places in welds which are not easily accessible.

sufficient, but where there is insufficient length in the parallel member, it can be heated red—if necessary—and if the operator takes sufficient care to see that he does not reach the danger point at which the frame might tend to upset. When heating the lower rails to obtain expansion of fractures in upper rails it is well to

have pedestal braces in place, in order to prevent distortion of the pedestal.

4. The frame is now ready for the pattern, which is made of yellow wax. This wax should be placed in a pan and warmed until it becomes plastic, or else melted entirely and then allowed to cool until it becomes plastic. Another way is to pour the melted wax in a small stream into cold water, almost immediately removing it with the hand and squeezing the water out.

The wax should be shaped around and between the parts to be welded, as shown in Fig. 1. If the ends of the sections are slightly warm, the wax will adhere better. Care should be taken to see that the entire space between and around the ends of the sections is filled with wax and that it contains no voids, so that after hardening, it will be able to withstand the necessary hard ramming of the mold.

It is necessary to provide a vent hole through the wax extending from the location of the heating gate to the riser. A convenient way to do this is to imbed a piece of woven rope not over ½ in. in diameter in the wax, which can be pulled out after the pattern is formed. Another way, frequently practiced, is to heat a rod or wire and force it down through the wax from the base of the riser to a point about opposite the heating gate and also force it in from the heating gate location to meet the other hole previously made.

5. The mold box, with perforated sides and bottom, should then be placed in position and securely blocked up so that all weight will be removed from the frame.

6. The operator is now ready for the molding material. The selection of a proper molding material is probably one of the most important parts of the entire thermit welding operation as upon this depends to a great extent the soundness of the weld. After a great deal of research, a molding material has been developed which exhibits both the necessary refractory qualities and the very necessary porosity after preheating. A further discussion of this and the formulas for this molding material are given on page 20.

The first time a thermit weld is made, such a molding material should be used throughout the mold. Thereafter, this molding material, once used, should be screened, sieved and re-used as backing in subsequent operations. New material should, however, always be used to line or face all portions of the mold with which the thermit steel will come into contact, and it is usual to make this facing about 1 in. thick. The molding material should, of course, be moistened to just the proper consistency to make it ram well.

7. In ramming the mold, place a small amount of molding material in the box and ram around the edges with a small rammer, or, better still, with a pneumatic bench rammer (which will save a great deal of time), working toward the center and keeping the molding material level, and *ram hard*. Too much emphasis cannot be laid on this point, for in the construction of the mold depends the

safety of the entire welding operation. The operator must be sure that the material is well rammed underneath the pattern, and that it is hard and firm at this point and at all points where it comes in contact with the wax and wooden patterns, and subsequently with the thermit steel. There should be a wall of molding material about 4 in. thick between the wax pattern and the mold box at all points, as the thermit steel is intensely hot and ample molding material should be provided to hold it.

8. A wooden gate pattern for the preheating opening should be set at the lowest point of the wax pattern and leading out to the front of the mold box, where an opening is provided for it. Where the sections to be welded together are of the same size, this pre-

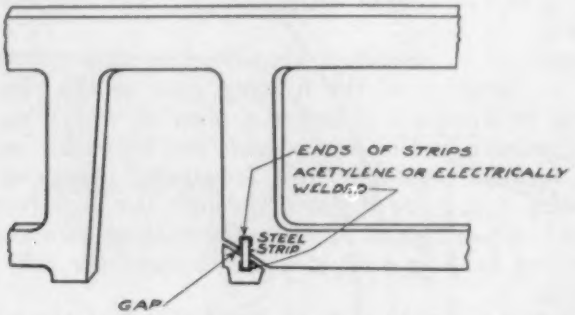


Fig. 7. Method of aligning broken heel of frame, preparatory to welding.

heating gate should be set directly in the middle of the lowest part of the wax pattern, so as to heat both sides of the frame equally; sometimes, however, it is necessary to weld a light frame section to a heavier one, in which case the preheating opening should favor the heavier section, which will require a longer time to heat than the light section.

9. With the preheating gate provided for, the pouring gate pattern is placed against it, and the junction of these two located about midway between the wax pattern and the shoulder on the heating gate. If these two wooden patterns are caused to fit neatly together, there will be less work later in removing the fin of sand at this junction point. It is important that all points of the interior of the mold and gates be hard, firm and smooth without projecting fins or ledges in the sand which might break off and be trapped in the thermit steel. Dimensions for these various patterns will be found in Table I, page 9.

Different operators adopt different "kinks" in ramming the mold, but the usual way is to ram "backing up" to or a little above the bottom of the wax collar, then trowel out the 1 in. space next to the wax collar where the facing should be and ram this hard with facing sand. In the same way, the backing and facing are rammed hard to a point above where the heating gate will be and a channel

troweled out for the heating gate to lie, and the heating gate pattern then pounded or tapped down with the rammer until it has sunk into the molding material to its proper position. More facing sand is then rammed on top of this heating gate, completely burying it; and on either side of this, more backing rammed even against the wax collar itself. When a depth of 2 in. or 3 in. above the heating gate has been reached, the approximately 1 in. next to the wax collar is again troweled out and facing put in and rammed hard. In a similar way, a round hole is dug down to expose the top of the heating gate pattern an inch or more away from the wax collar, the pouring gate pattern carefully placed, and the space around the pouring gate then filled up with facing to the level to which the mold has already been rammed. This method of ramming in, backing and cutting away those portions where it must be replaced with facing, is then followed until the mold is completely filled, the riser pattern placed in practically the same manner as was the pouring gate pattern, and the top of the mold hollowed out to form a basin, as will be described in more detail later.

10. At the highest point of the wax pattern place the riser pattern. If there is more than one high point, place a riser pattern over each as the function of a riser is to hold a supply of steel which will remain liquid for a considerable period of time and take care of all shrinkage, so that when a "pipe" is formed, due to shrinkage, this pipe will appear in the riser and not in the weld. The riser also acts as a depository for loose sand or other foreign matter which may be washed into it by the thermit steel in passing through the mold and prevents this material from clogging in the weld. It sometimes happens that welds are made at a point where a wooden riser pattern cannot be withdrawn conveniently and in such cases a riser may be formed out of wax, which will melt out during preheating with the rest of the wax pattern.

11. After the mold is all rammed it should be hollowed out on top so as to form a basin in which the slag may collect and not overrun the mold box. The operator should cut a channel or trough in the top surface of the mold, connecting the top of the pouring gate and the top of the riser so as to cause the first slag overflowing on top of the mold to quickly run across to the riser and thus, while the metal is still liquid, equalize the pressure on the pouring gate and the riser. He should then vent the mold thoroughly by forcing a vent rod made from 8-gage or 10-gage steel wire down through the molding material to within 3 in. or 4 in. of the bottom. Care should be taken to see that the vent holes do not touch the wax collar or the gates, otherwise the vent holes will fill with steel and will therefore be useless as a vent. These vents should be as numerous as practicable and some of them, possibly larger than the rest, should be carried up to each of the top corners of the mold box where they will continue to stay open even after the slag has completely filled the basin on top of the

mold. The purpose of these vents is, of course, to allow the escape through the mold of any air which may have been trapped in the falling steel and any gases formed in the mold on account of the high temperature of this liquid steel.

12. The operator should now lightly rap the gate, riser and preheating opening patterns and draw them out carefully, wiping away any loose sand that might tend to fall into the holes. A molder's slick, trowel and lifter are very useful in this connection. After the pouring gate and heating gate patterns have been removed, smooth off carefully any sharp edges or fins at the top of the pouring gate and at the junction of the pouring and heating gates. This latter point can best be reached by means of a ¼ in. rod slightly curved at its end. After preheating, the sharp edges and fins at the junction of the heating gate and wax collar and at the base of the riser can be similarly smoothed off.

13. The mold is now ready for preheating. The burner of the thermit preheater should be set so as to point into the heating gate of the mold and about one inch from the opening, and the blast applied. It is best to start easily at first, as too much of a blast would tend to "cut" the mold. When heated the wax will burn out, leaving a perfect mold just the shape of the wax pattern. The operator should now cover the various openings on the top of the mold so that nothing can fall into them, and lift the crucible into position, securing it firmly, with its bottom directly over and about 3 in. above the center of the pouring gate, so that the metal when tapped will fall into the hole itself and not on the sloping sand surrounding the mold. If the crucible cannot be placed directly over the pouring gate, construct a runner as shown in Fig. 6, to lead the steel into the pouring gate and then proceed to plug and charge the crucible in accordance with instructions on page 19.

The heat should be kept going until the mold is thoroughly dried out and the parts to be welded are brought to a good, red, workable heat, such as would be required if the frame was to be hammered. (For description of preheater see Fig. 2.)

14. While the preheating is in progress and after having made sure that the crucible has been thoroughly dried out and possibly is even still warm from this drying operation, the charge of thermit and additions should be placed in the crucible. Each bag of thermit should be thoroughly mixed by dumping it into a pan and turning the pile over a number of times before putting it into the crucible. The thermit cannot be properly mixed after it is in the crucible. It is important to put in a few handfuls of thermit first, before dumping in the rest of the charge, so as not to disturb the plugging material. No ignition powder should be added until the thermit charge is ready to be ignited.

15. Too rich a flame during the early part of preheating may not be harmful but, especially toward the end, the operator should see that no excess oil is used so that the lean flame will tend to burn

out, from the molding material, any oil which may have penetrated during the early part of the preheating. When it is assured that the frame is at a good workable heat, he should remove the burner and direct it down the riser so as to blow out any sand or dirt which may be in the mold. If the riser is difficult of access, the burner may be directed down the pouring gate. The operator should now examine as carefully as possible the interior of the mold to locate any possible loose sand particles and be sure that these are blown out before the heating gate is plugged. The preheating hole may then be plugged with a sand core or an iron plug. If an iron plug is used care must be taken to see that it is clean and not rusted, tin-galvanized, etc. Many operators make these sand cores by wrapping a piece of heavy paper around the proper part of the

Fig. 8. Gap cut out preparatory to welding.

Fig. 9. Thermit reaction.

Repairing broken slab of large crankshaft by means of thermit welding.

heating gate pattern, sliding the paper off carefully and then ramming thermit molding material into the form so made and baking slowly and carefully over the mold during preheating.

Whatever form of plug is used, it should be heated slightly before using so as to be sure that it is thoroughly dry. The plug should then be placed carefully into position, making sure that the subsequent backing up of the plug cannot force it by the shoulder in the heating gate and thus possibly interfere with the bottom of the pouring gate. A short plug will do but it should fit neatly in the heating gate. Such a short plug could then be backed up with

molding material, lightly tamped into the heating gate, and this in turn backed up with several shovelfuls of molding material rammed in between the mold box and the steel plate provided for the purpose. This will prevent any possibility of the thermit steel running out through the preheating opening.

All heating apparatus should be removed to a safe distance, while the thermit reaction is in progress. Occasionally on account of moisture in the crucible lining or in the thermit itself, there will be some splashing out of slag from the crucible during the reaction, and it is well therefore to see that the riser and all openings other than the pouring gate are covered with small pieces

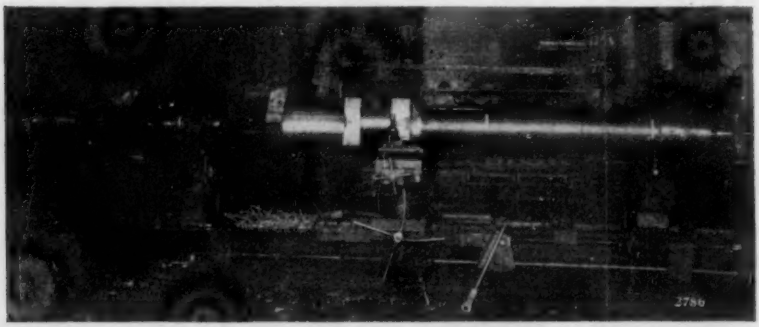


Fig. 10. Machining a large, three throw Diesel engine crankshaft thermit-welded for South Norwalk Electric Works, South Norwalk, Conn.

of sheet iron to prevent this slag by any chance from dropping into the mold and adhering to the sections to be welded.

16. Mix the contents of the ignition powder can and then place one-half teaspoonful of ignition powder on top of the thermit in the crucible (thermit will not ignite from the heat of the preheater and the reaction cannot be started without the use of the ignition powder). The ignition powder can be ignited directly with a match, but as this is more difficult and the sudden flare liable to burn the operator's fingers, it is preferable to partly bury the head of the match in the ignition powder and light this with another match or with a thin iron rod heated red hot. The crucible should be tapped when it is noted that the reaction is over, which usually takes from 25 to 35 seconds. Tapping is accomplished by knocking up the tapping pin which sets in the bottom of the crucible, Fig. 3, using for the purpose the tapping spade or a flat piece of iron 1½ in. x ¼ in. x 4 ft. long.

17. It is important that the expansion previously obtained by jacking or by heating a parallel member should be maintained until the weld has solidified sufficiently to enable it to resist the tendency of the frame to upset it. On the other hand, it is probably even more dangerous to resist the shrinkage of the metal in the weld during solidification, so that the operator should use careful judgment in this matter. It has been found that usually a loco-

motive frame weld after an hour, although still at a good red heat, is sufficiently strong and solid to take this pressure if the pressure is not applied too suddenly, so that rather than take any chance of straining the weld during solidification, it is advisable to release the jack carefully after half an hour. The operator, by watching the tram marks, can readily determine whether the weld is being upset or not; if not, the jack should, of course, be completely removed.

Where the expansion has been obtained by preheating a parallel number the preheater can be removed when or shortly after the weld is poured. If properly timed in this way, the two parallel members will contract together satisfactorily. The operator should be sure that the contraction of the weld is not resisted by the jack or otherwise because, at these high temperatures, the weld material has little strength and may be damaged by this resistance.

18. The mold should be allowed to remain in place as long as possible, preferably over night, so as to anneal the steel in the weld, but in case of necessity it can be removed after two or three hours in light frame welds, or in about four hours in heavier frame welds.

19. After removing the mold, cut off the metal in the riser and pouring gate with an oxy-acetylene torch, or drill through these sections and knock them off.

20. *Automatic Crucibles.*—The thermit reaction takes place in a magnesia tar lined crucible (Fig. 3), which has at the bottom a hard burnt magnesia stone ("AA"). This latter, again, has a tubular opening, into which a small magnesia stone or so-called "thimble" ("BB") of conical form is made to fit. This thimble provides the channel through which the liquid thermit steel is poured. To replace the thimble, it can be easily removed by carefully knocking upward and a new thimble inserted. It is safer to use a new thimble for each reaction.

21. *Plugging the Crucible.*—The bottom of the crucible (Fig. 3) is closed before charging by first inserting the thimble ("BB") wrapped with one thickness of uncreased paper. This is plugged with plugging material as follows: The tapping pin ("F") is suspended through the thimble and over this are placed the asbestos washers ("E") and then the metal disc ("D") is pressed lightly down upon the asbestos washers. All this is then covered with about ½ in. of refractory sand ("C").

22. *Preventing Contraction Stresses.*—It should always be borne in mind that the thermit weld will contract when it cools and this contraction must be allowed for in advance, either by spreading the parts mechanically with a jack or spreader or by heating opposite members so as to spread the parts. If this fact is always kept in mind by the operator satisfactory results are assured.

Welding Fractures In Vertical Members.—The welding of a fracture in a vertical frame member sometimes presents difficulties, but this operation is simple if care is taken in cutting out the

fracture and in placing the risers so that no gases, slag or sand will be trapped in the weld.

The best practice is to cut out the fracture as shown in the drawing, Fig. 4, and set the pouring gates and risers as indicated. This practice permits of a good washing action for the thermit steel so that any loose sand that might be in the mold will be carried into one riser or the other.

It has not been found advisable to place any of these risers directly up against the frame at the upper edge of the collar because this reservoir of heat so close to the frame is likely to melt the section away above the weld. The risers are therefore placed ¼ in. or so down from the edge of the collar.

It is evident that there will be a pocket above the level of the base of the riser in which air would be trapped when the mold is filling rapidly with steel. It is very important therefore that this extreme top edge of the collar entirely around the section should be completely vented to the top of the mold so as to allow the air to escape freely as the mold is filling. It is advisable to lay in, alongside of the frame, thin wooden shims, 1/16 in. to ⅛ in. thick which are withdrawn after the mold is rammed and, thereby completely vent the top edge of the collar all the way around. It is true that this space will be filled with steel but the fin will be so small that it will chill against the frame and not weld to it and therefore, can be readily chipped off upon completion of the weld.

Aligning Broken Heels of Frames.—In case of fractured heels of frame legs, the broken part is held in alignment with the frame by means of two or three steel strips about 3 in. by 1 in., one laid flush against each side of the frame (see Fig. 7). About ½ in. of the two ends of these strips are welded to the surface of the two parts by means of the oxy-acetylene torch or the electric arc.

Molding Material for Thermit Welding.—The molding material should be especially adapted for thermit welding, and when used in accordance with the proper thermit practice, will almost completely prevent the occurrence of blow holes and similar defects and assure sound welds. This material, designated as "thermit molding material," is quite different from ordinary molding material and in all thermit work, either this, or a substitute having the same qualities should invariably be used.

The design of the new molding material is based on the theory that good silica sand will stand the heat of the thermit reaction and that the weakness in all molding material is the clay binder. Therefore there should be as little clay as possible in the mixture, in order to make the mold more refractory and to increase its porosity. It is therefore logical to turn toward the use of a plastic clay instead of a fire clay, as formerly. The sand and plastic clay are ground together in a foundry pan, or muller, with the intention of coating each grain of sand with a minimum thickness of clay. This procedure has resulted in a good, clean molding material, which can be rammed hard in the mold, which will stand

up well under the preheating flame and which is extremely porous to the gases generated in the mold, and which results in a sound weld with a very clean exterior. Although suitable molding material can be made by increasing the clay content slightly and mixing the clay and sand thoroughly by hand, it is not so good as that made with a smaller clay content in the foundry pan or muller.

The mixture now being used is composed of the following: 3 parts clean, sharp silica sand (100 per cent of which should pass through a screen having an 0.03 in. square opening, and 40 per cent of which should be retained on a screen having an 0.012 in. square opening), mixed with 1 part Welsh Mountain plastic clay.

Fig. 11. Showing welded neck and wooden pattern in place.

These parts are first thoroughly mixed in the muller together with 1/40 part glutrin by volume and sufficient water (1/12 part) to bring to the proper consistency. If mixed by hand, only 2½ parts by volume of sand should be used and the sand and clay must be dried before mixing (being careful not to subject the clay to a temperature higher than 400 deg. Fahr.) and thoroughly mixed before adding the glutrin and water. The glutrin should be mixed with the water before adding to the sand and clay.

In case a plastic clay fatter than the Welsh Mountain be used, the mixing, of course, will have to be more thorough and less clay used. Welsh Mountain clay is being used in the present mixture because in carefully run tests it has proved to be the most refractory.

Preheater for Thermit Welding.—In order to obtain uniformly successful results with the thermit process, it is important that a proper preheater be used for drying the molds and bringing the sections to be welded to a good red heat before pouring the thermit steel. A preheater has been developed operating with compressed air and either kerosene or gasoline which is especially adapted to the purpose. This preheater is furnished with either single or double burner types as desired. Needle valves are of original design and give an exceedingly close regulation of the mixture

Fig. 12. The molten wax is poured into the space between the wooden patterns and remaining parts of wabbler ends.

of air and fuels, enabling perfect combustion to be obtained at all times.

For locomotive work the double burner preheater should always be used, as it permits the use of one burner for heating and the other for expanding. This is most necessary where one member of a double bar frame is to be welded, as while the part to be welded is being preheated, the other part can be heated with the second burner and expanded to avoid shrinkage strains when the weld cools.

Nothing has been found to take the place of kerosene or gasoline

in this preheating as they give clean, hot flames with no tendency to deposit carbon. Under no circumstances should crude oil or fuel oil be used on account of the danger of carbon deposits; and all gaseous fuels should be avoided because they burn at the tip of the burner and in the heating gate, overheating this part and insufficiently heating the upper part of the section and mold. The vaporized kerosene can be made to burn at will at any part of the

Fig. 13. The completed weld before removing pouring gates and risers —no machining necessary.

mold according to the richness of the flame and the velocity of the air.

CRANKSHAFT REPAIRS

Crankshaft Repairs.—Heavy crankshaft repairs present a very interesting application of the thermit process. In making a crankshaft weld the parts of the shaft are supported in the proper position by "V" blocks mounted on a machined bed plate. The fracture is cut out and a space provided in the usual way for the thermit steel. The shorter end of the shaft is offset in such a way that when the metal in the weld contracts it will be drawn back into

approximate alignment, the longer end of the shaft being held rigidly in position and the shorter end being allowed freedom of motion. It is obviously impossible to guarantee the free end coming back into perfect alignment. It is, therefore, always understood in connection with crankshaft repairs that a light cut will

Fig. 14. Three ends welded and one end not welded—note the part built up.

have to be taken on the shorter end of the shaft to bring the completed shaft back into alignment and the bearing involved relined to compensate for the slight reduction in shaft diameter. In the event of an end main bearing being broken off it is usually found preferable to discard that piece and weld on a new billet slightly larger in diameter so that after the weld is made it can be turned down to the original diameter in bringing the shaft back into alignment.

Shafts almost always break because of some flaw or defect in the material. This is often an old forging crack in the case of built up shafts which gradually spreads until finally the shaft

gives way. A shaft with such a flaw has no factor of safety at all. If all surplus metal of the weld is machined off, the shaft will have a factor of safety which will be found ample for all purposes for future serviceability and the owner will really have a better shaft than originally, because the flaw has been located and

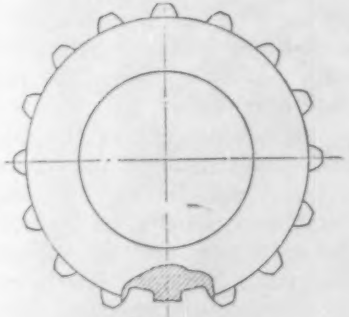


FIG. 1

FIG. 3

FIG. 4

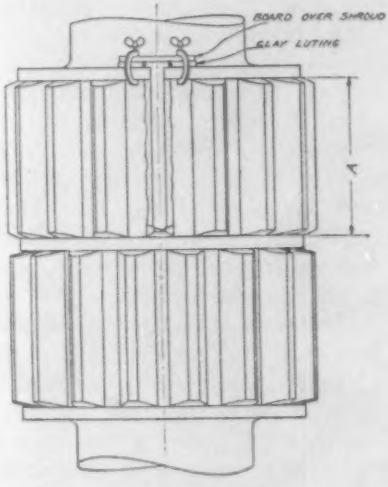


FIG 2

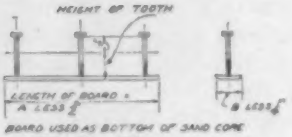


FIG. 5

FIG. 6

1803

Fig. 15. Preliminary steps in welding teeth in pinions.

1—Section through broken tooth, showing usual line of fracture.
2—Showing method of cutting shroud and attaching board and clay luting for welding shroud.
3—Sand core rammed to form mold for one-half of tooth.
4—Both cores in position and filled with wax.
5—Design for board to support bottom of sand cores.
6—Section and elevation of sand cores used as one-half of wax pattern mold.

eliminated and the rest of the shaft has been thoroughly tested. Figs. 8, 9 and 10 illustrate some typical crankshaft welds by the thermit process.

STEEL MILL REPAIRS

Steel Mill Repairs.—Steel mill repairs, which are of particular interest, comprise the welding of new necks to rolls and pinions, the welding in of new pinion teeth to replace teeth broken out, the building up of worn wabbler ends of rolls and pinions, the repair of broken roll mill housings, charging peels, large shafts and the repair of heavy sections in general.

Welding Necks On Rolls and Pinions.—When it is necessary to add new necks, it is best practice to cast a new part, slightly oversize and weld this on in the usual way. After welding, the part is machined to proper diameter and alignment.

Building Up Worn Wabblers.—This represents one of the most important uses of thermit in steel mill practice as it permits of economically reclaiming the worn parts of wabbler ends of both rolls and pinions. Of course, if the wabblers are too badly worn away or broken, it is then best to weld on a new neck as outlined above, but where the wear is not too great, the worn parts can be rebuilt with thermit steel with most satisfactory results. However, special wabbler thermit should always be used; this has been designed especially for the purpose and produces a steel which, while sufficiently hard and tough to stand the severe service to which it is subjected, yet is machinable.

A wax pattern representing the part to be replaced has to be formed on the wabbler ends and two different methods for conveniently making this wax pattern are in common use in the various mills. One method consists in making wooden patterns which exactly fill the spaces between the pods (Fig. 11). These, of course, are made from either new rolls or from the patterns from which the rolls are cast. With these wooden patterns in place, the wabbler end is then surrounded with a piece of sheet iron and molten wax poured into the spaces between the wooden patterns and the remaining parts of the wabbler ends (Fig. 12). The wooden patterns are then removed and a sand mold rammed up in the usual way, preheated and poured. The pouring gates are connected at the bottom with a connecting ring which can be made out of wax so that the steel will flow uniformly to the various parts of the mold (Fig. 13).

An alternative method and one which is greatly preferred by many of the mills is to make a mold for casting the wax out of a mixture of Portland cement and plaster of paris. This is cast around the end of a wooden pattern corresponding to the roll to be repaired and is made in two parts. The plaster of paris mold is allowed to overlap the end of the roll or pinion so that when placed in position on the worn wobbler end it practically centers itself. When this mold of Portland cement and plaster of paris is put on the worn wabbler end, the intervening spaces, i.e., the worn parts, are filled with molten wax in the same way as when wooden patterns are used. Of course, it should be understood that both the

wooden patterns or the plaster of paris mold represent permanent equipment and can be used repeatedly where the same type of roll is under repair. It is the usual practice for a mill to carry several

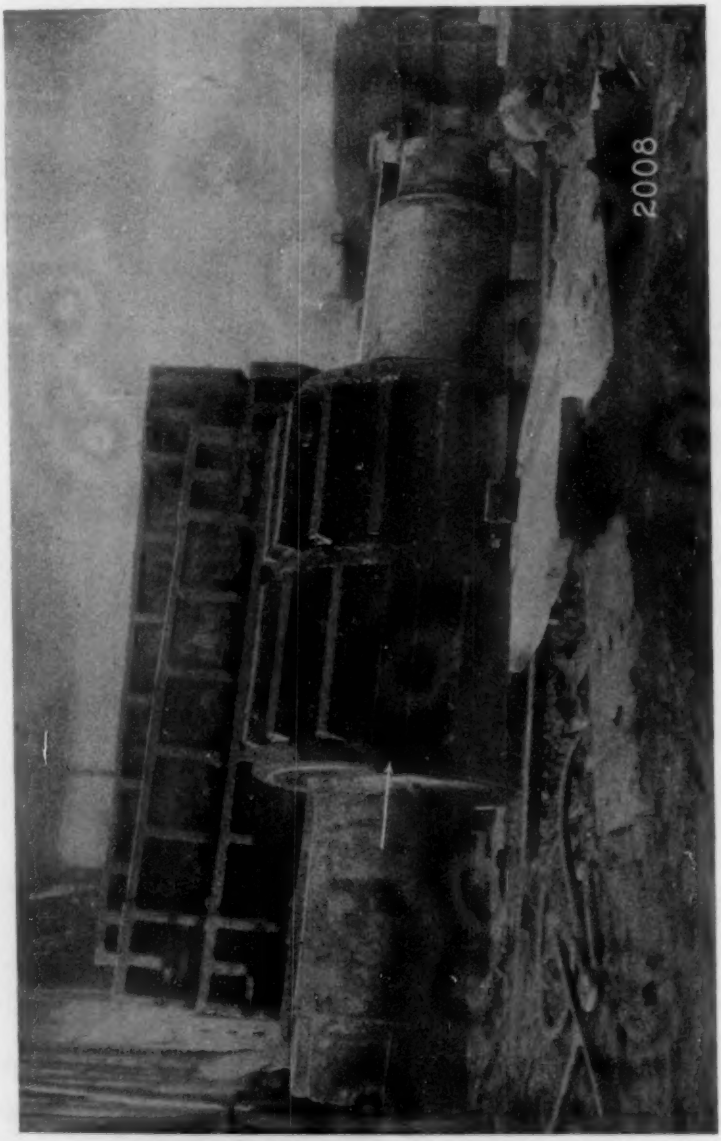


Fig. 16. Tooth cut out of pinion.

different styles of these molds in stock to fit the various wabbler ends which they have occasion to repair. By doing the work in this manner, the steel can be added so accurately that no machine work is required (Fig. 14). It is not uncommon for wabbler ends

repaired in this manner to outwear the original ends owing to the extreme hardness of the special steel produced from wabbler thermit.

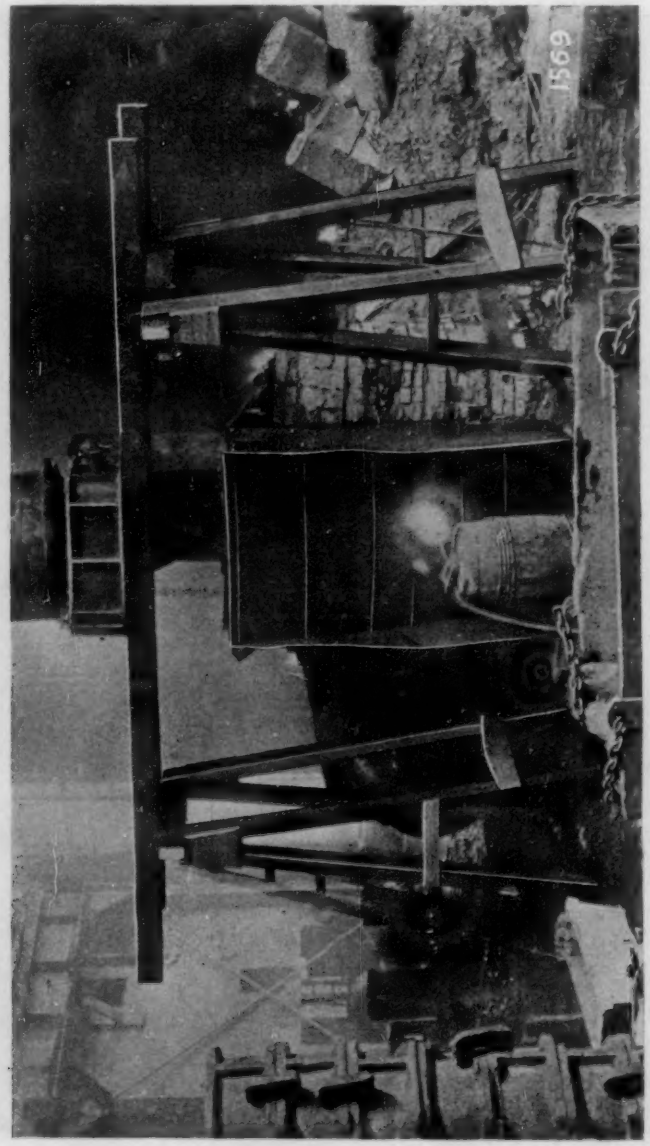


Fig. 17. Mold box, brick furnace and crucible in position and pinion being preheated.

Welding New Teeth In Large Pinions To Replace Teeth Broken Out.—The repairs usually consist of replacing teeth or parts of teeth which have broken out. They are peculiar in that the tooth is a comparatively small projection on an extremely heavy steel cast-

ing. For this reason, if the repair were attempted by the ordinary methods, i.e., if the casting were preheated at the weld only as covered in previous instructions for making thermit welds, the heat would be carried away into the casting so quickly, especially during the interval of removing the preheating burner and tapping the crucible, that in most cases a poor weld would result. Further-

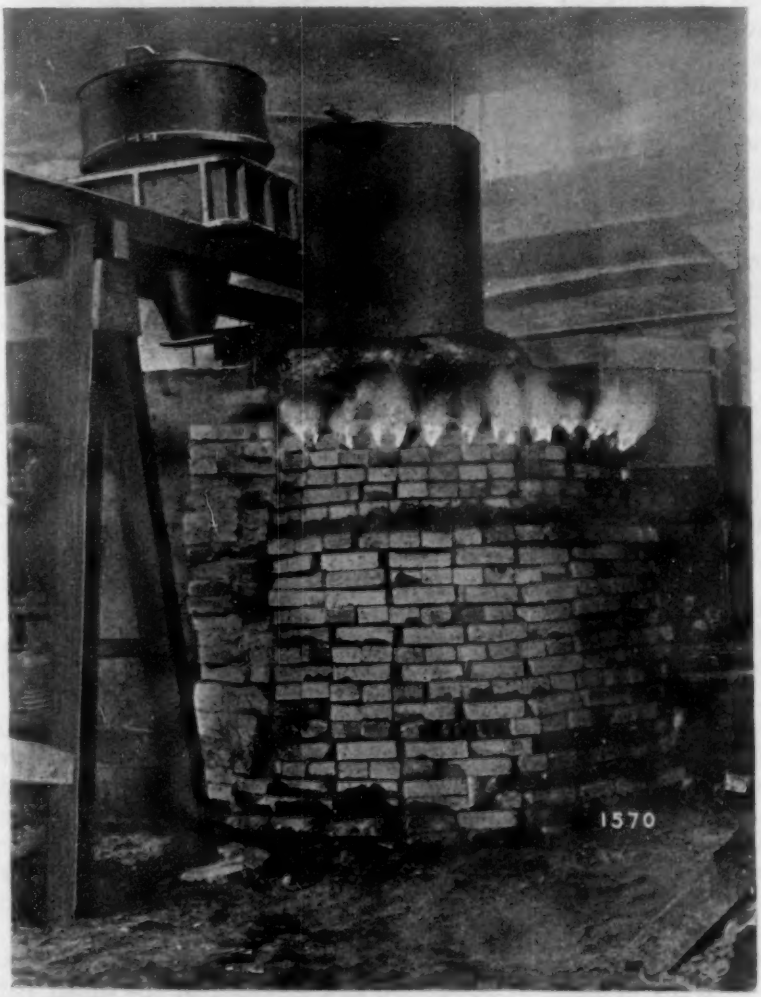


Fig. 18. Rear view showing preheating of body of pinion in brick furnace.

more, there would be great danger of cracking the pinion. Everything possible must therefore be done to conserve the heat at the weld and to do this efficiently, it is necessary that the whole pinion should be heated to a red heat. This may be done by bricking in the heaviest part and preheating it by means of oil or gas burners

conveniently placed while the part to be welded is being preheated in the regular way. Care should be taken, however, to bring up the heat slowly as otherwise there is danger of cracking the pinion.

In making all welds where a relatively small amount of thermit steel is to be added to a heavy steel casting or where one, or both, of the parts to be joined is considerably heavier and larger than the thermit steel part, it is necessary to take special precautions to secure thorough amalgamation of the thermit steel with the heavier part, especially at the extreme edges of the line of junction where in service the greatest strain will come. The slightest imperfection at this line of junction or extreme fiber will cause a tear to start in service which will cause a fracture of the welded part. A perfect weld on this extreme fiber is made more difficult by the fact that the metal in the weld always shrinks a little more than the white hot steel of the pinion due to the slight difference in shrinkage between molten steel and white hot steel. It is necessary, therefore, that the fusion be obtained for a considerable depth even at the extreme edge of the thermit steel. Fusion at this point is more difficult because the heat of the thermit steel comes from one side only and not from all sides as it does near the center of the weld.

For all the foregoing reasons it is desirable to increase as far as possible the surface exposed to the thermit steel in the width of the weld. This at the same time produces edges or corners which melt more readily and thus aid in the fusion. These edges may be readily produced by cutting out a groove or slot in the main body of the pinion at the center part of the root of the tooth broken out. This slot should be half the width of the tooth in depth and also in width, i.e., if the tooth to be welded in is 6 in. wide at its root, the slot should be made 3 in. wide by 3 in. deep. The most economical way to cut this slot is to place the pinion on a planer and machine it out.

Referring to Fig. 15, the patterns shown in sub Fig. 3 should be made and fitted as indicated, after which sand should be properly mixed for cores, using two parts of building sand to one of fire clay, and this should be sifted through a No. 4 mesh riddle and should then be moistened a little more than would be necessary if it was to be used in ramming a mold. If this mixture does not draw well,, more clay can be added, as the clay will not affect the wax in any way.

The pinion should then be placed in a horizontal and level position with the missing tooth section in the center of the upper part. The core can then be rammed after first thoroughly cleaning between the teeth which are to be used as the guides, and which should be nearest the top.

The pattern is then placed in the bottom of the space between two teeth and held with lag screws, after which the core is rammed firmly to a point ¾ in. above the height of the tooth, as indicated in the drawing. The most convenient way to do this ramming is to

use an iron or wooden strip ¾ in. high on top of the tooth. The core should then be "slicked" from that height to the level of the opposite tooth. The idea of providing this extra height is to hold enough wax for shrinkage.

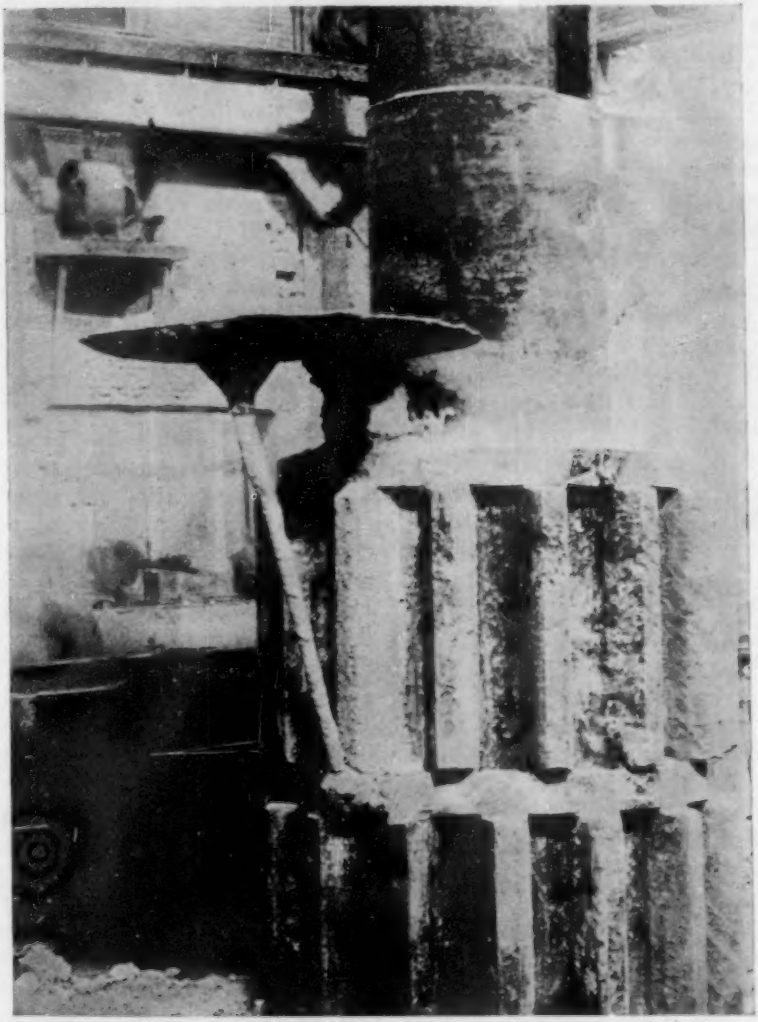


Fig. 19. Finished weld showing metal in pouring gate and riser.

After the core is thoroughly rammed it should be carefully drawn by two men, using the end lag screws for the purpose. It should then be set carefully upon a box wide enough to support it over the entire length. It is advisable to force a little sand under it in order to keep the core stationary. Two cores are necessary in the making of one tooth and the second core is made in exactly the

same way as the first. When these cores are ready the operator should start at one end of the core and remove ¼ in. from top to bottom over the entire surface, as shown in the drawing. After this has been done the surface should be "slicked" to make it smooth and marked so as to be sure of placing it in its proper position. It should be understood that this sand is removed from the side of the core which does not come in contact with the wax.

The object of this cutting is to make the mold slightly larger so as to take care of the shrinkage of both wax and thermit steel.

The pinion should then be mounted vertically for the welding operation. In this mounting great care should be taken that the pinion is properly supported so that there will be no danger of its settling under the added weight of the mold box. This can be accomplished in the following manner:

First dig a hole in the ground the proper size to receive the neck of the pinion. Then lay two "tee" rails across the top of the hole so that they will come underneath the shoulder of the pinion. If the ground is not sufficiently hard to properly support the tee rails, steel plates can be placed underneath in order to prevent the rails from settling into the ground.

The cores can now be placed in position, one on each side of the missing tooth, making sure that the sides of the core from which the ¼ in. has been removed are resting tightly against the adjacent teeth. A weight should then be placed partly on adjacent teeth and partly on the core to hold it in a correct position. The end can then be stopped off with fireclay mixed to the consistency of putty, after which the mold, i.e., the interior of core, can be filled with small pieces of wax about 1 in. square, after which melted wax can be poured in, thus filling up all spaces between the small pieces of wax.

Care should be taken not to have the wax too hot, as it is only necessary that it should be hot enough to run freely. If it is boiling hot it will tend to eat into the sand and make a rough tooth.

The mold should not be disturbed until the wax has set, which will be from three to four hours after pouring. In the meantime, however, other work can be done, such as mixing sand for the mold, assembling mold box, etc.

If the pinion is shrouded, the wax pattern to provide the thermit steel reinforcement on this shroud can be put on at the same time that the wax tooth is formed, it being only necessary to roll a long clay rod, about 1 in. in diameter, and lay it against the pinion 3 in. away all around from the space cut through the shroud, and then back it up with a board large enough to extend above the top of the tooth.

This board can be held in place with two "C" clamps, and luted with clay between board and cores on the inside so that the wax will flow to its proper level. (See 2, of Fig. 15).

This work is all done in green sand, and if care is taken while making the pattern for the new tooth, with this method, there will

be very little finishing required on the wax, thereby effecting a saving of about a day on each welded tooth.

When the wax pattern is finished, the mold box should be placed in position. This mold box should be wide enough to take in two teeth on each side of the tooth to be welded. Three staybolts should go through the box, as indicated in the drawing on page 25, so as to keep the box from spreading when it is being rammed.

The mold box should then be firmly held to the pinion by means of two ½-in. thick straps bolted to the mold box. The lower strap should be about 3 in. wide and should encircle the lower shroud.

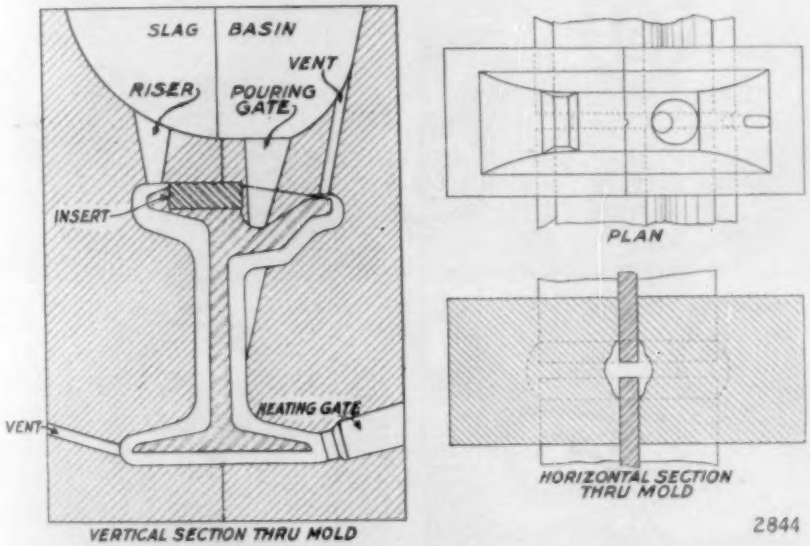


Fig. 20. Construction of two-part mold used in thermit rail welding.

The upper strap should be about 14 in. wide and should encircle the upper neck, just about the upper shroud. Both straps should be insulated from the pinion by ramming up a 3-in. space between strap and pinion with good sand mixed well with fire clay, which will not crush easily. This precaution will then hold the box tightly to the pinion.

The operator should now ram up the mold box, allowing for a preheating gate, a pouring gate and a riser in accordance with previous instructions. It is important that the heating gate, the inner end of which connects the pouring gate to the weld, be extended to the very lowest point of the weld in order to make sure that this part be filled up with thermit steel.

When this operation is completed, construct a brick furnace around the exposed part of the pinion and about 2 in. away from the teeth. Next place a sheet iron casing around the exposed neck on top so that the casing rests on the strap which clamps the mold box. This casing should be 6 in. larger in diameter than the neck

and about 4 in. higher. Ram sand between the casing and the neck and cover the top with a layer of sand 4 in. thick. In this way, the entire pinion is insulated.

The next step is the preheating. To preheat, place a burner at the bottom of the brick furnace and start with a very mild heat. This is necessary so as to avoid heating the pinion too quickly, thus causing internal strains which might result in cracking the pinion. After the pinion has been thoroughly soaked with heat, the fire can be increased to a good sharp heat so as to bring the entire pinion to a good blood red or about 1200 deg. Fahr. While the

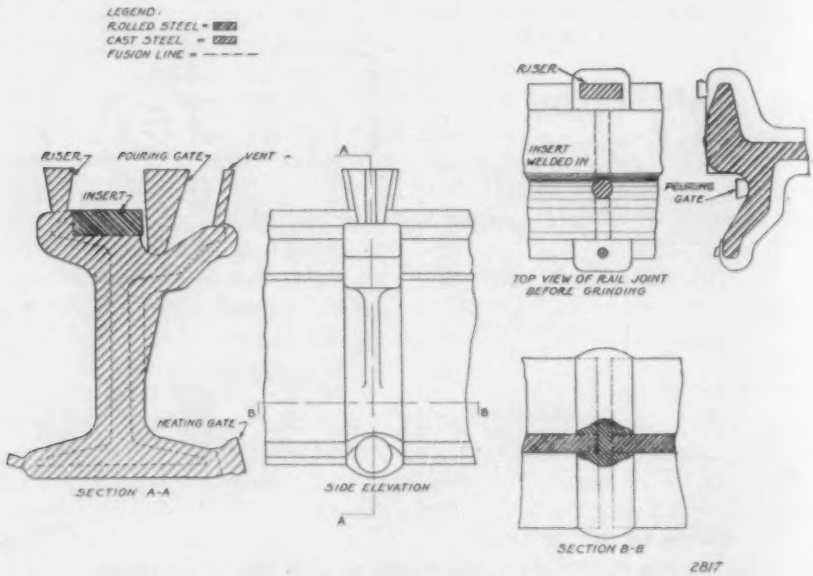


Fig. 21. Views of thermit rail weld, gates and risers.

heating is in progress the crucible should be mounted and charged and the weld poured in the usual way.

WELDING RAILS

Welding Rails with Thermit.—A thermit rail weld is made by pouring superheated steel obtained by the thermit reaction into a mold surrounding the rail ends at the joint. This thermit steel melts all parts of the rail section with which it comes into contact and, on cooling, solidifies with them in a homogeneous weld. An insert cut from a rolled section of similar analysis to that of the rail itself is placed between the heads at the running surface and the lower and back part of this insert are fused into the thermit steel. (In some installations, this insert is provided by allowing the head of one rail to extend across the gap; this is accomplished by under-cutting the head of one rail to provide the gap.) The mold is so constructed, however, that the head of the rail and the

top part of the insert are not melted but are merely brought to a welding heat, the result being a butt weld between the sides of the insert and rail heads due to the pressure exerted upon them by the expansion of the rail from the intense heat in the weld and by the contraction of the thermit steel. When the weld has been made, the running surface is ground and the weld is ready for service.

Laying Rails Preparatory to Welding.—Rails should be laid so that the joints come between ties and with a gap of approximately

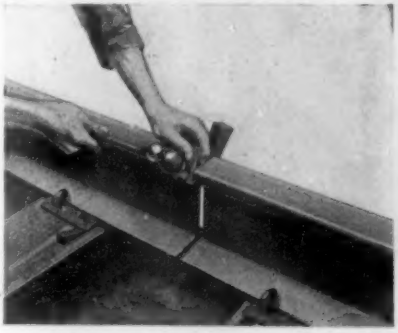


Fig. 22. Driving insert between rail ends—Tee rail.

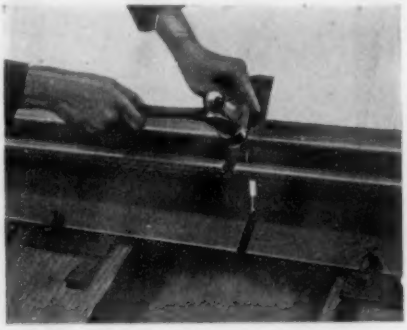


Fig. 23. Driving insert—Groove rail.

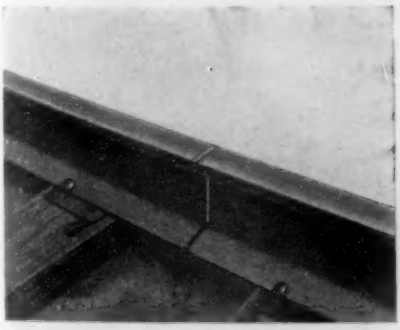


Fig. 24. Insert in place—Tee rail.

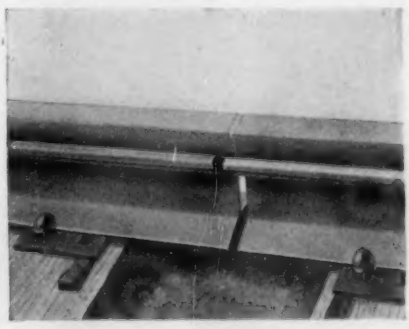


Fig. 25. Insert in place—Groove rail.

½-in. between the rail ends. The rails should be thoroughly cleaned for a distance of about 4 in. from each end, which can be accomplished by wire brushing or by sand blasting. The ends of the rail heads must be entirely clean and, where necessary, filed smooth where they come in contact with the insert. It is important that the ends be bright at this point to insure a good butt weld.

Following this cleaning process, the rails should be brought into proper surface and alignment, care being taken to keep the ends a trifle high, so that when a straight-edge about 30 in. long is centered over the joint, there will be a space of about 1/32-in. between the ends of the straight-edge and the surface of the rail directly under it. This slight raising of the rail ends has been

found necessary in practice, as it assures proper alignment and surface after grinding. Metal wedges driven between the ties and rails are used for this purpose.

The joint is now ready for the insert. The insert should be

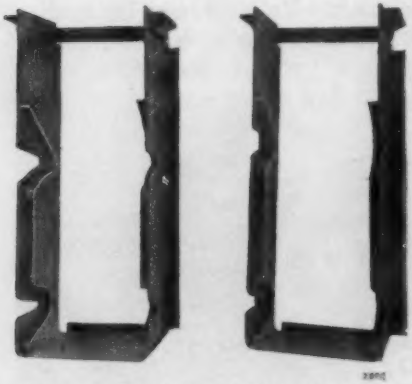


Fig. 26. Self-luting mold box halves—Inside view.

Fig. 27. Self-luting mold box—Outside view.

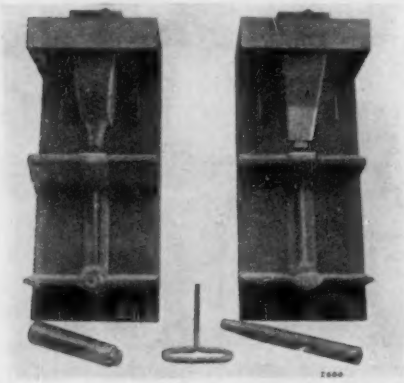


Fig. 28. Pattern for making molds. Below, from left to right: Heating gate pattern, vent rod, sprue cutter.

Fig. 29. Empty mold box halves placed on pattern.

thoroughly cleaned on its surfaces which will come into contact with the rail heads; this means the removal of any dirt, rust or anti-rust solution. In order to eliminate, as far as possible, contraction stresses in the welded rail, a wedge should be driven between the rail ends, as shown in Figs. 22 and 23, so as to spread them as far as possible. A convenient way consists in driving the wedge between the rails on the outside of the head. An insert of proper thickness is then driven tightly into place. This insert should project about 1/16 in. above the head and beyond the gage line. The wedge should then be removed and the insert will be

held firmly in position due to the elastic tension of the compressed rails. (See Figs. 24 and 25).

Preparing Molds.—The mold (for design see Fig. 28) is made in two parts with a vertical parting face. The parts are made by ramming molding material (which is a mixture of sand and clay) into sheet iron mold boxes, Figs. 26 and 27, over a specially de-

Fig. 30. Ramming mold.

Fig. 31. Mold box halves rammed.

Fig. 32. Removing core from mold.

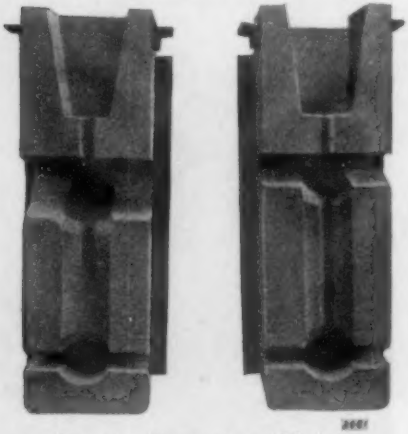


Fig. 33. Rammed mold halves.

signed aluminum pattern, the dividing line of the molds being in the center of the rail web.

The pattern, Fig. 28, is made in two parts, one of which represents the base, web and lip of the rail, or the inside, and the other representing the base, web and head of the rail, or the outside. There is a riser over the outer edge of the head and the pouring gate is positioned so that the metal enters the mold at the bottom of the groove, or just outside of the gage face.

In ramming the head or outside mold, the pattern is laid back down, and the corresponding half mold box placed on top of it where it will be centered by the clips provided for the purpose.

(See Fig. 29). A small amount of molding material is thrown in and packed hard underneath the luting strips, which are the strips on the inner sides of the mold box following approximately the contour of the rail. The molding material is also packed tightly under the riser pattern and when this is completed, more molding material is added and rammed in until the box is filled, when the top surface is smoothed off with the trowel or by some other means, cutting a groove about ¼-in. deep by 2 in. wide across the top sur-

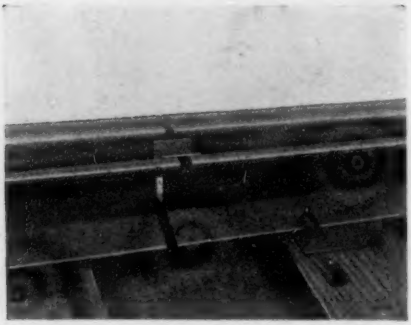


Fig. 34. Cardboard strip inserted in groove of groove rail.

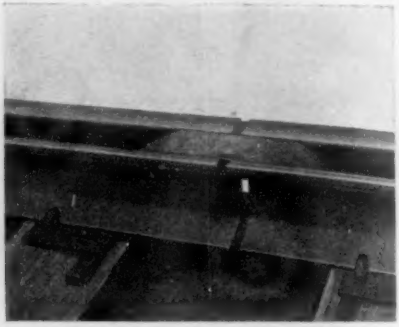


Fig. 35. Molding material applied to fill groove of groove rail.

Fig. 36. Applying molds to rail—Tee rail.

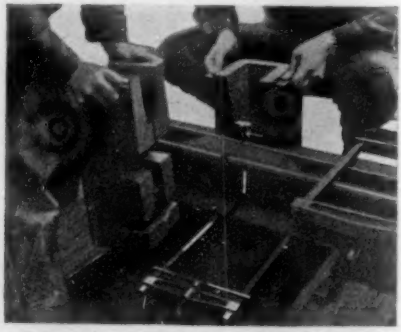


Fig. 37. Applying molds to rail—Groove rail.

When applying molds to rail the centering head of the mold (see arrows) should be placed directly over the insert.

face of the mold on a line just above the head of the rail; this is about the line where the upper clamp will be applied and is needed to provide clearance between the clamp and the molding material. A vent is now provided midway between the sides of the mold box and ranging slightly downward to strike the edge of the base by forcing the vent rod in at this point. The riser pattern is then rapped lightly to loosen it and carefully withdrawn by means of the handle provided for the purpose. The entire combination of half mold and pattern is now turned over so as to bring the backboard of the pattern upward. The pattern is then rapped lightly

on each side and carefully withdrawn from the mold. Figs. 30 to 33 show these operations.

The pattern for the inner half or lip side with its corresponding mold box should then be rammed in the same manner as the head or outside half except that a wooden heating gate pattern is pro-

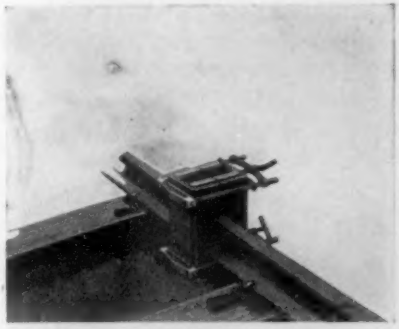


Fig. 38. Mold box halves applied to Tee rail.

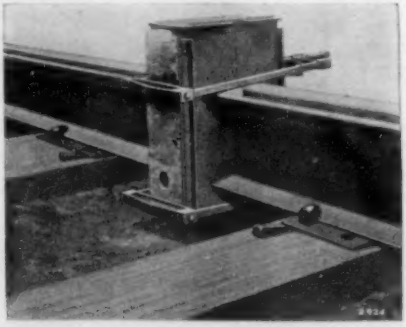


Fig. 39. Mold box halves applied to Groove rail.

Fig. 40. Inserting preheating gate plug in mold.

Fig. 41. Pushing preheating gate plug into mold.

vided to fit a dowel pin on the base of the rail. A vent is provided by forcing the vent rod down through the hole in the top of the pouring gate pattern until it meets the high point of the lip. Then the heating gate and pouring gate patterns are rapped lightly to loosen them and carefully withdrawn. The rest of the operation is identical with that of the outside half. Sometimes in removing the pattern from the mold, small edges of the mold are broken off. These should be carefully replaced, using the molder's tools pro-

vided for the purpose. Any sharp edges of molding material which might later break off in the preheating should also be smoothed off at this time.

Molding Material.—It is important that proper molding material be used, as thermit steel flows into the mold in a highly superheated

Fig. 42. Inserting taper pin plug in mold.

Fig. 43. Ramming taper pin plug into mold.

Fig. 44. Knocking off riser and pouring gate.

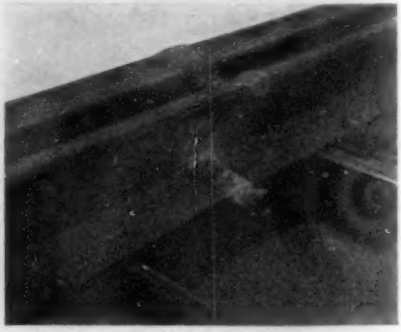


Fig. 45. Weld before grinding, inside view—Groove rail.

condition, much hotter than ordinary molten steel. It is recommended that a high grade silica sand mixed with sufficient fire clay to act as a binder be used, the proportion depending upon the quality of sand and clay. Usually two parts sand to one part clay makes an entirely satisfactory mixture but sometimes it is necessary to increase the proportion to half and half. As little fire clay as possible should be used, as it tends to destroy the porosity in

the mold and prevents the proper escape of gases. The sand and clay should be thoroughly mixed dry, then passed through a ten-mesh riddle and moistened just enough to pack well.

Applying Molds—Groove Rail.—In welding a groove rail, a cardboard strip should be pressed tightly into the groove so as to conform to its contour and liberally span the gap (Fig. 34), and the groove is then packed flush with molding material (Fig. 35). (See that two clamps are handy; one between the ties under the joint, the other close at hand). Carefully adjust the two parts of the mold to the rail—one half at a time—being sure that they are properly centered over the joint. To facilitate this adjustment, the molds are constructed with a centering bead on one half and

Fig. 46. Weld before grinding, inside view—Tee rail.

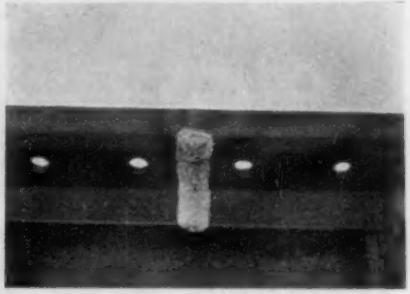


Fig. 47. Weld before grinding, outside view—Tee rail.

a groove to receive it on the other half. These should be directly over the insert. (See Fig. 37). Great care should be taken in applying the molds so that none of the edges are broken in the application. The operator should now apply the top clamp, allowing it to rest on the top of the rail and draw the boxes slightly together and then apply the lower clamp to the extreme bottom of the mold (see Fig. 37) and draw both clamps up until the boxes meet at the top and the bottom. Care should be taken to see that the molds are drawn up tight so as to prevent the liquid steel from running out.

When the mold is in place, the pouring gate is completed by cutting an opening through the sand which is packed in the groove. This is done with a sprue cutter provided for the purpose, which is pushed down the gate already in the mold until it strikes the cardboard, leaving a clean hole free from any loose particles of sand or other foreign matter.

Preheating.—Adjust the preheater nozzle in its holder so that it is directed into the heating gate of the mold and about 1-in. away from it; the nozzle should be aimed slightly downward. Start the preheater and open the needle valve which permits the kerosene vapor to mix with air. When a sufficiently rich mixture is obtained, it can be lighted with a railroad torch or other means. It is well

to run a fairly rich mixture until the burner is well started, after which the needle valve can be closed slightly until the mixture burns with a blue flame. No adjustment of air is necessary, the

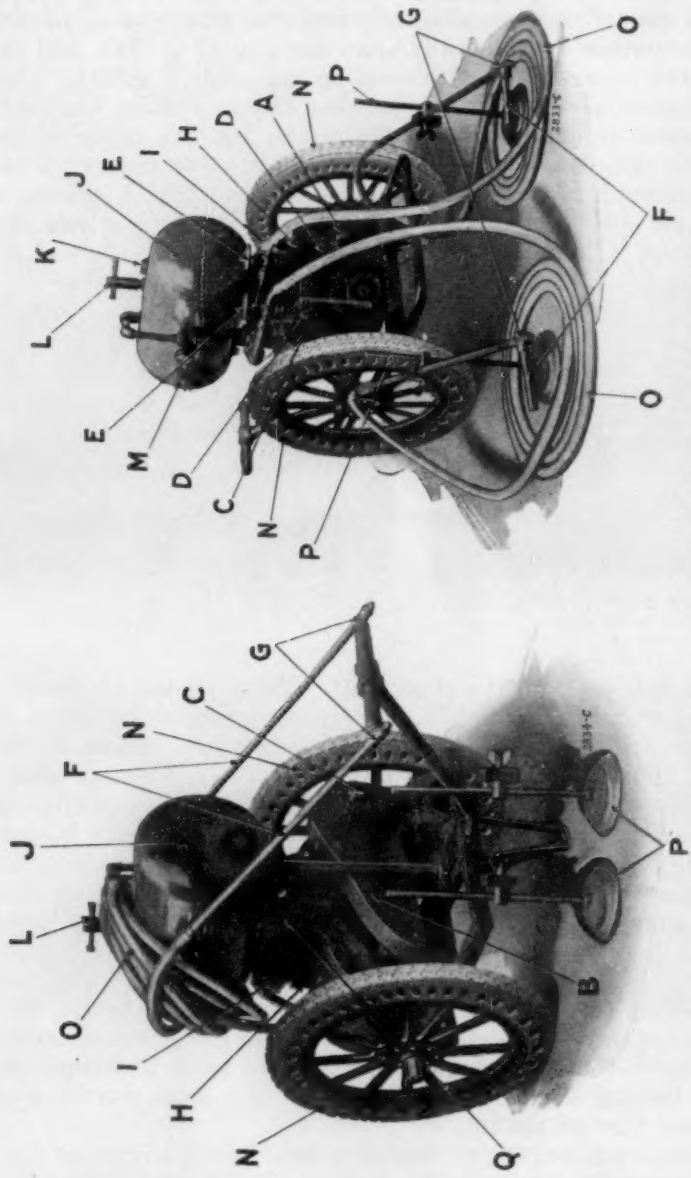


Fig. 48. Light-weight, Double Burner Preheater for Thermit Rail Welding.

A. Motor.
B. Silent Chain.
C. Blower.
D. Resistance Heater Units.
E. Needle Adjusting Valves.
F. Nozzles.
G. Mixing Heads for Nozzles.
H. Terminal Connector.
I. Snap Switch.
J. Fuel Tank.
K. Oil Level Gauge.
L. Plug for Filling Hole.
M. Air Pressure Gauge
N. Cushion Tired Wheels.
O. Rubber Hose Lengths.
P. Nozzle Holders.
Q. Fuse Box.

only adjustment being on the fuel. Immediately after starting the preheater, it is important to see that all vents in the mold are open and this precaution is facilitated by pushing a wire into each.

Adjusting Crucible.—While preheating is in progress, the crucible should be placed in position. First, clamp the shoe of the crucible holder to the rail about 8 in. from the outside of the mold box, then set up the standard and apply the ring. The crucible is next set into the ring and swung into position over the heating gate, and the position of the upright and the height of the ring adjusted so that the spout of the crucible comes directly over the

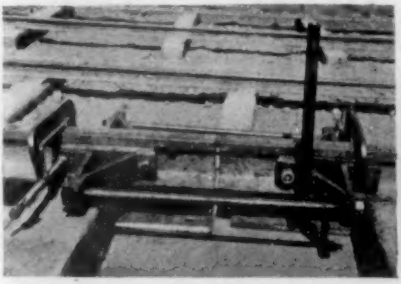


Fig. 49. Rails held in clamps prior to applying molds.

Fig. 50. Showing molds applied and crucible in position.

Fig. 51. New rails welded and ground alongside of track.

pouring gate and within about 3 in. above the top of the mold. The crucible is then swung aside until required. In the meantime the crucible can be plugged and charged in accordance with the instructions already given. Thermit for rail welding is supplied in semi-waterproof paper bags, each holding sufficient thermit to make a perfect weld on the rail section for which it is designed.

When the preheating is almost completed, about half a teaspoonful of ignition powder is placed on top of the thermit and the cover replaced on the crucible.

Completing the Weld.—The time required for preheating varies somewhat, but is usually between 20 and 25 minutes. The base of the rail will be brought to proper temperature more quickly than the head. It is advisable when the base is red hot to place the burner nozzle about 1-in. inside of the heating gate, thus driving the more intense heat up through the mold toward the head. If

the burner in this position allows the base to cool slightly before the head has been properly heated, the burner may be shifted to the original position to again bring up the heat on the base. Preheating in this way should be continued until the rail section is at a *bright red heat.* The burner is then directed down the riser

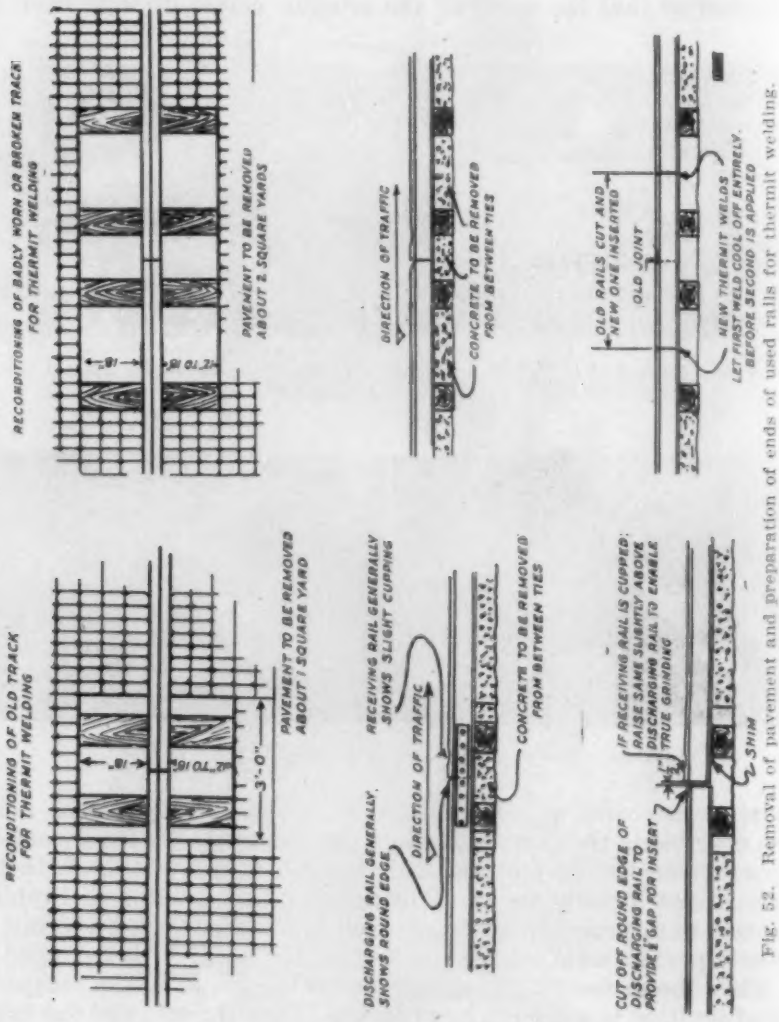

RECONDITIONING OF BADLY WORN OR BROKEN TRACK FOR THERMIT WELDING
PAVEMENT TO BE REMOVED ABOUT 2 SQUARE YARDS
DIRECTION OF TRAFFIC
CONCRETE TO BE REMOVED FROM BETWEEN TIES
OLD RAILS CUT AND NEW ONE INSERTED
OLD JOINT
NEW THERMIT WELDS
LET FIRST WELD COOL OFF ENTIRELY BEFORE SECOND IS APPLIED
RECONDITIONING OF OLD TRACK FOR THERMIT WELDING
PAVEMENT TO BE REMOVED ABOUT 1 SQUARE YARD
3'-0"
DISCHARGING RAIL GENERALLY SHOWS ROUND EDGE
RECEIVING RAIL GENERALLY SHOWS SLIGHT CUPPING
DIRECTION OF TRAFFIC
CONCRETE TO BE REMOVED FROM BETWEEN TIES
CUT OFF ROUND EDGE OF DISCHARGING RAIL TO PROVIDE ¼" GAP FOR INSERT
IF RECEIVING RAIL IS CUPPED RAISE SAME SLIGHTLY ABOVE DISCHARGING RAIL TO ENABLE TRUE GRINDING
SHIM

Fig. 52. Removal of pavement and preparation of ends of used rails for thermit welding.

and the pouring gate in order to blow out any particles of loose sand or foreign matter that may have fallen into the mold.

The heating gate and back vent openings are now plugged as quickly as possible to conserve the heat. The heating gate is plugged by inserting the metal cup until it rests against the shoulder provided to receive it, and then backed up securely with molding material rammed in tight. The small vent at the back of

the mold is plugged with the metal taper pin which is forced in tight and backed up with molding material. (Figs. 40 and 43).

Igniting Thermit and Pouring.—Toward the end of the preheating operation, a wire or rod should be placed in the riser so that it will be heated and can be used in starting the thermit reaction. The crucible is now swung into position over the pouring gate and when everything is ready, the red hot rod touched to the ignition powder, thus starting the reaction. When the thermit reaction is completed (in about 15 to 20 seconds), the crucible is tapped by striking the tapping pin sharply upward with the tapping spade provided for the purpose.

The mold should be allowed to stand for at least 10 to 15 minutes

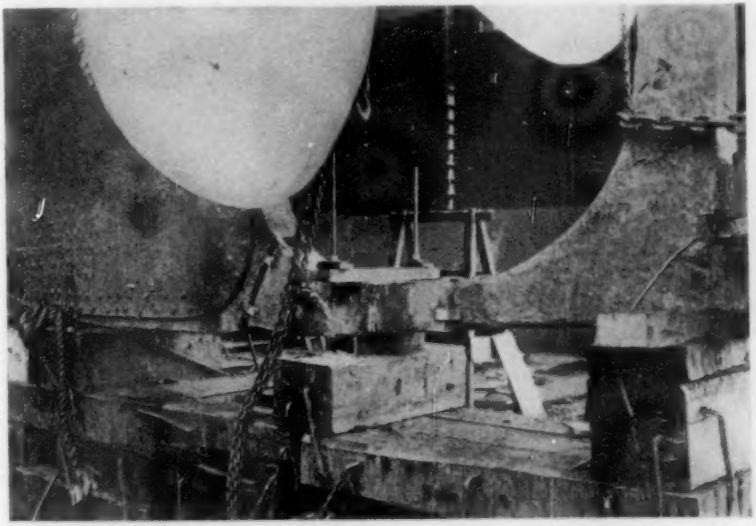


Fig. 53. Welding stern frame of a large freighter.

or until the steel has thoroughly set, when it can be removed from the rail. The steel in the pouring gate, riser, heating gate, etc., can now be cut off with a hot chisel and a sledge (Fig. 44). It is recommended that the operator take advantage of the heat in the weld by hammering the top surface of the insert and riser while the weld is still hot. This hammering should be carefully done, of course, so as not to injure the rail surface and, if done thoroughly, very little grinding will be required. A small amount of grinding, both on the head and on the gage, is always necessary, however, in order to bring the rail to a true surface.

The welding work should proceed in this way and it is obvious that work on other joints can be carried on at the same time so that the labor will be most economically used. As the work proceeds quite rapidly, it is advisable to skip every fifth joint so as to allow the welded section of rail to contract, and then return and

weld these expansion joints when the intermediate welds have cooled to the temperature of the rail. On very hot days it is better not to weld these expansion joints until the next day when the rails have shortened on account of the lower night temperature. It is also well to drive the inserts into these expansion joints as early as possible after the cool of the night so as to prevent the gaps from closing even partly before the joint can be welded.

Welding Girder Rail.—The procedure for welding girder rail is practically the same as that for welding groove rail, described above, except that the lip of the girder rail being horizontal obviates the necessity of using cardboard strips and of ramming

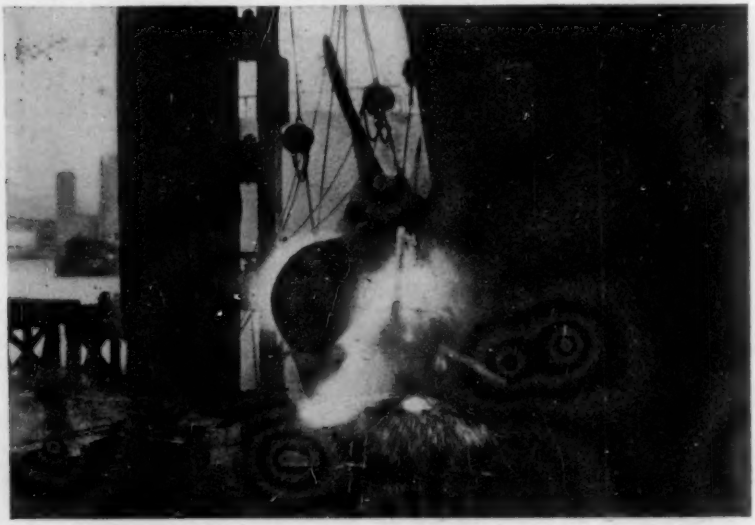


Fig. 54. Pouring the thermit steel.

molding material into the groove as this can readily be provided for in the pattern and in the mold.

Welding "Tee" Rail.—The operation of welding "Tee" rail is likewise the same as that for welding groove rail except for the slight difference in the construction of the mold on account of the absence of the groove. This is shown in Fig. 36.

Welding Old Rail.—The welding of an old rail by the thermit process is entirely feasible and very simple providing the rail is not too badly corroded and pounded at the joints. Where the rail is in good condition and only slightly pounded, the weld can be made without cutting in a new piece of rail. In such cases, the receiving rail can be raised until the lower part of the cup is on a level with the running surface. The end of the discharging rail can then be cut off about ½ to ¾ in., thereby eliminating the bat-

tered end and at the same time providing a gap for the thermit insert. This procedure, after grinding, entirely eliminates the battered joint and restores a running surface equal to that of a new rail. The method of making the weld is identical with what has already been described excepting that in some cases it is necessary to do a little hand-luting with fire clay around the edges of the mold boxes, in view of the fact that it is quite impossible to design patterns which will conform exactly to the contour of rail which is partially worn.

Where the joint is very badly pounded, it is advisable to cut in a short piece of new rail and make two welds. In such cases, cutting

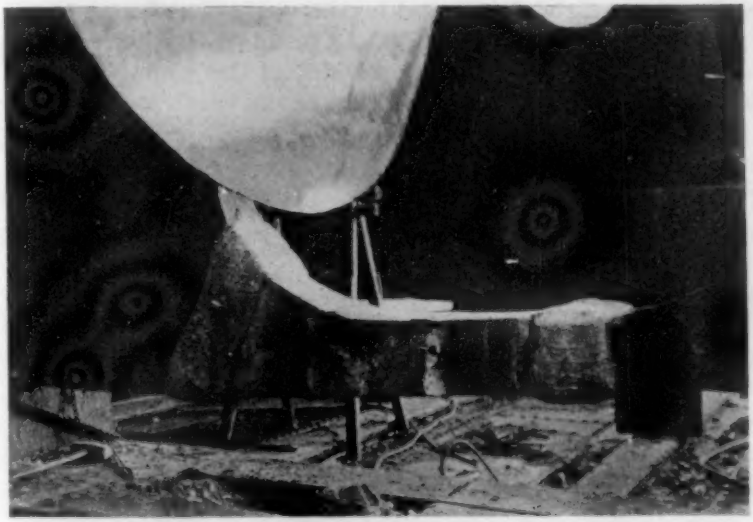


Fig. 55. Weld on stern frame completed.

in not less than four feet of rail is recommended. The second weld should not be made until the first weld has cooled.

The steps of the operation of repairing worn rail and the space required for this work are shown in Fig. 52.

Welding Rails Before Installing Them in the Track.—Where track reconstruction is being undertaken in such cases where street car headways are too close to justify using temporary cross-overs, where re-routing on parallel streets is impracticable or where expensive types of track, as for example, the conduit system, have to be relaid, involving prolonged and costly night work, it may be found feasible to reduce labor costs very materially and accelerate the speed of the work by laying the rails to be installed along the side of the street, parallel to the track, and weld several lengths

together during the daytime. They can then be transported close to the edge of the track during the early hours of the morning, the old rails removed and the new installed. If there be insufficient time to weld the free ends of the welded rail lengths to the ends of the rails already installed, these joints can be temporarily bolted and thermit-welded during another night.

The number of rails per unit which can be first welded together at the side of the street will be limited by the length of space uninterrupted by cross streets along the curb adjacent to the place of installation.

In preparing the rails at the side of the street for welding a convenient method, if space permits, is to mount them on temporary ties as shown in the accompanying illustrations. These ties, however, need not be closer than 10 to 15 ft. apart, except at the joints, where there should be a tie on each side of the joint. The rails are then held together by means of clamps, as illustrated, which hold the rails in alignment and the insert in position while the weld is being made.

The joints may then be welded in the usual way and the welds can be ground before the rails are transferred to the track proper. The lengths of rails which can be welded in this way are only limited by local conditions; and in practice stretches of over 3000 ft. have been welded and then placed in position between the old running rails. It is then a simple matter to substitute the newly welded rails for the old.

Where conditions permit, this method has proved to be a very economical way of installing newly welded track and the welding itself can progress with great speed. (See Figs. 45 to 47).

MARINE REPAIRS

Marine Repairs.—The thermit process is used extensively in the marine field for welding broken stern posts, stern frames, rudder frames, rudder posts, shafts, davits, anchors and propeller struts of steamships. It is hardly necessary, however, to set forth any detailed instructions covering this work as these welds do not usually present features which would require a different procedure from that already described; usually it is a case of making a thermit weld at the point of fracture. However, in some cases where there is more than one fracture, or where there may be considerable defective metal to be replaced, it is the best practice to make up a new billet or forging to replace the defective part and weld this in position by means of two thermit welds. The thermit process has been approved by the leading marine underwriters for this class of work. Figs. 54 and 55 illustrate the welding of the stern frame of a large freighter.

WELDING PIPE WITH THERMIT

Process Adapted to all Sizes and Weights of Pipe up to 6 inches in Diameter.

Preparing the Ends of the Pipe.—The pipes should be cut with square ends before preparing them for welding. If the pipes are threaded it is necessary to cut off the threaded parts.

The ends of the pipes should then be accurately faced so that they are square, smooth and bright. When a considerable number of welds are to be made, this can best be done in a lathe, but where a small number of welds are involved or where it is not convenient to use a lathe, the facing can be accomplished by means of a small portable pipe facing machine.

Directions for Operating Pipe Facing Machine.—First rotate the pipe facing machine hand wheel to the left, in order to back off

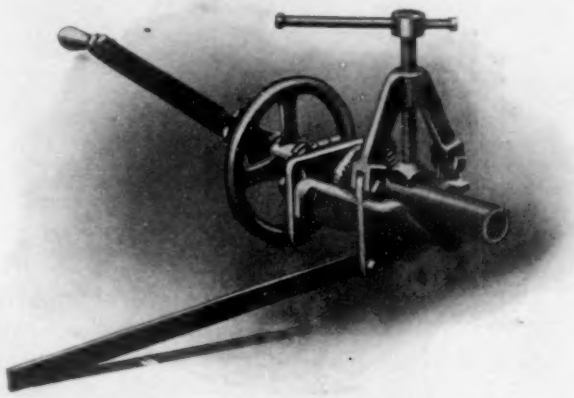


Fig. 56. Pipe clamped in facing machine.

the cutter as far as possible, but not so far that it will be impossible to disengage the small jaw clutch. This procedure will allow the cutter to be gradually fed forward during the pipe facing operation.

Clamp the pipe facing machine to the pipe so that the end of the pipe to be faced is about $\frac{1}{8}$-in. away from the cutter. (Fig. 56). Slide the handle of the machine inward so as to engage the jaw clutch and revolve it to the right so as to gently force the cutter against the pipe. If the cutter is forced too hard against the pipe, it will be almost impossible to revolve it by means of the ratchet handle, while if forced against the pipe too lightly the maximum speed of operation will not be attained.

Draw the hand wheel back so as to disengage the clutch and by means of the ratchet handle slowly revolve the cutter to the right, taking care not to revolve the cutter too quickly, as chattering will

result, especially as the cut becomes lighter. The speed of operation should, if possible, be uniform, and this is the main object of the ratchet handle which allows the uniform and continuous rotation of the cutter. There are places, of course, where the continuous rotation is impossible. This would be the case where the pipe was located close to a wall or where other pipes nearby would interfere.

As soon as the first cut has been taken, the hand wheel should be moved into engagement with the jaw clutch again and the cutter again pressed against the pipe end. This operation should be continued until the end of the pipe is accurately faced.

After slight experience with the machine the operator can determine by the "feel" of the hand wheel when the pipe has been completely faced, but until such time the operator should back off

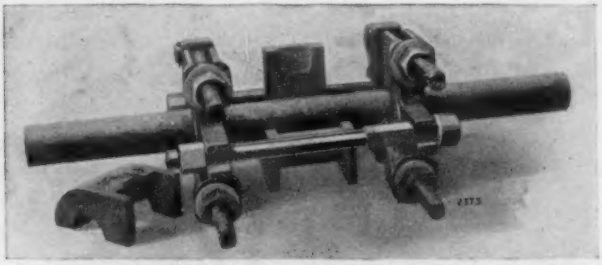


Fig. 57. Pipes held in clamps. Mold partly assembled.

the cutter to inspect the pipe ends. The chips from the cutter should be removed occasionally during the facing operation.

The steel casting through which the spindle operates is split and provided with an adjusting screw. This should, of course, be left as loose as possible, but if in operation, the cutter should feed in toward the pipe while being revolved; the adjusting screw should be tightened to prevent this "self-feeding." This tightening of the adjusting screw will clamp the brass sleeve and prevent its rotation unless intentionally rotated by means of the jaw clutch.

The "self-feeding" of the cutter is caused by friction on the thrust face directly behind the cutter and a drop of oil should frequently be placed on this thrust face to prevent undue friction.

The cutter should be sharpened occasionally by means of a flat carborundum stone rubbed uniformly across the whole face of the cutter; two or three passes completely around the cutter will be sufficient. When the teeth of the cutter have become so flattened by sharpening that the stone does not seem to further affect them, the cutter should be reground rather than to continue operation with it in this condition. At any time, in case the cutter should become nicked, it should not be used until this nick has been removed by means of regrinding.

Making the Weld.—In welding coils or bends, rig up suitable supports to keep the pipe in alignment. Where the pipes are close together in coils it is possible to spring out the pipe to be welded so as to permit of adjusting the mold and clamps.

Place one pair of clamp jaws around the end of each pipe about 4 or 5 in. from the end and tighten them securely by means of the nuts and wrench provided for the purpose.

If the pipe ends have become tarnished after the facing operation, they should be brightened by using a fine piece of emery cloth

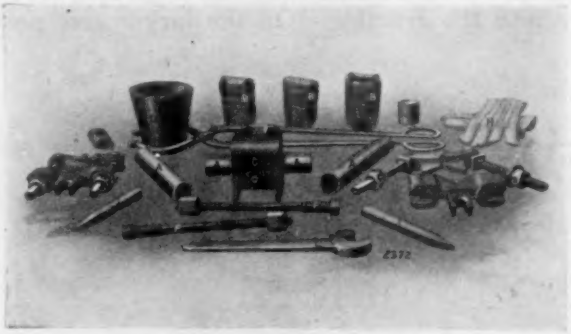


Fig. 58. Materials for welding pipe.

AAAA—Pieces of pipe; BBB—Welding portions of thermit; CC—Cast iron mold; D—Crucible; EE—Clamps; FF—Drawbolts for clamps; G—Crucible tongs; H—Gloves; J—Ignition powder; K—Dark glasses; L—Wrenches for tightening nuts of clamps and draw bolts.

or flat carborundum stone. In no case, however, should they be touched with a file or with the fingers on the faced surface.

Butt the ends of the pipe together and place the longitudinal clamp bolts in position. Draw up the nuts on these bolts by simultaneous applications of the wrenches, being careful to see that the tension is equally divided so that the pipe ends butt together accurately all around their circumference. Draw up the bolts to obtain a good close fit between the abutting pipe ends and then turn the nuts one complete revolution. (Fig. 57).

The operator should next place the lower mold casting under the pipe with the joint in its center and block it up with wedges or earth to hold the mold castings securely in place. The upper casting may then be placed over the joint which is now ready for welding. Place the crucible tongs on the ground conveniently in front of the mold and set the crucible in the jaws of the tongs. It is most important that this crucible should be thoroughly dried before using and if it is a new crucible it is advisable to burn a pound or so of thermit in it and pour the contents out on dry sand, as this is the quickest and most convenient way of drying the crucible. The operator should have the handles of the tongs toward him in order to pour the crucible when the reaction is completed.

If double tongs are used, as is sometimes necessary with the larger sizes of crucible, a helper should stand opposite the operator in readiness to help pick up the crucible at the proper time and to assist the operator in the act of pouring.

In order that the sight may not be blinded momentarily by the incandescence of the liquid thermit steel and slag, both men should wear blue glasses to protect their eyes.

The operator should then take one of the welding portion bags of thermit and pour about two-thirds of the contents into the crucible. The remaining part can be placed in a hand scoop for feeding in during the thermit reaction or can be poured from the paper bag directly into the crucible. On the larger size portions it is

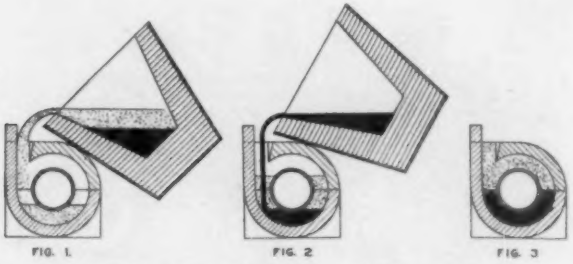


Fig. 59. Thermit pipe welding operation.

1—Slag flowing into mold and coating outside of pipe and inside of mold.

2—Slag in mold and steel following, displacing slag in bottom part.

3—Both slag and steel in mold but steel separate from pipe and mold by film of slag.

advisable to provide a sheet metal shield in front of and about 8 in. over the top of the crucible as a protection from the radiated heat during the reaction. The thermit is then fed through an opening, about 6 in. in diameter, in the top of the shield. Having, therefore, his portion partly in the crucible and the remainder in the scoop or bag, the operator should place one-half teaspoonful of ignition powder on top of the thermit in the crucible and ignite it by applying a parlor match immediately after striking and before the head is burned off. This will ignite the ignition powder, which in turn will start the thermit reaction going. After the reaction is well started the operator should add the rest of the thermit from the bag or scoop, trying to keep about one-half of the surface of molten material covered with unburned thermit, and pouring in a steady stream without interruption until all of the thermit is in the crucible. He should then immediately grasp the crucible with the tongs, obtain a firm grip, and pour the contents into the cast iron mold. The pour should be made the instant the thermit has all reacted.

The crucible and tongs should then be set aside and a short time allowed to elapse for the thermit mass to bring the pipe ends to

a welding temperature. It has been common practice, shortly after pouring, for the operator to apply the wrenches to the clamp nuts and keep a constant pressure downward on these to determine when the pipe begins to soften and then wait 10 to 20 seconds, depending on the weight of the pipe, before drawing up on the clamps to force the pipe ends together to effect the butt weld. In order to eliminate any uncertainty from this part of the operation and to make the procedure as simple and as sure as possible, Table II, indicating just how long the operator should wait after pouring the thermit steel and before drawing up on the clamps, has been prepared. This

TABLE II

Nominal Size of Pipe	Standard Pipe		Extra Heavy Pipe		Double Extra Heavy Pipe	
	*Time between pouring and drawing up		*Time between pouring and drawing up		*Time between pouring and drawing up	
Inches	Minutes	Seconds	Minutes	Seconds	Minutes	Seconds
½	0	14	0	20	0	40
¾	0	22	0	30	1	00
1	0	33	0	45	1	30
1¼	0	45	1	00	2	00
1½	0	55	1	15	2	30
2	1	00	1	30	3	00
2½	1	30	2	00	4	00
3	1	40	2	20	4	40
3½	1	55	2	40	5	20
4	2	10	3	00	6	00
4½	2	20	3	20		
5	2	30	3	40		
6	3	00	4	40		

*Minimum time.

table covers all the sizes and weights of pipe for which the thermit process is adapted.

After waiting the required time, as shown in Table II, the operator should draw up on the draw bar nuts one complete revolution (four quarter turns).

After the clamps have been drawn up, the mold should be allowed to remain in place for three or four minutes longer, after which the clamps can be removed and the cast iron mold knocked away from the pipe by means of a hammer. The thermit steel and slag will come away from the pipe with the mold and can be knocked out of the mold afterwards.

Care must be taken in every case that a complete welding portion be used, as only the full measure of thermit will give a good weld.

It is advisable where joints are being welded in quantities to have several molds so as not to use molds continuously while hot. It is also advantageous to allow the mold with its contents of steel and slag to remain on the pipe for a considerable time before removing. If they can be left for from 10 to 15 minutes it is all the better.

By having several molds and a number of crucibles the welding

can progress very rapidly and two men working together, one facing up the pipe ends, with the pipe facing machine, and the other following and doing the welding, can make an average of about 50 pipe joints per day on the smaller sizes of pipe.

The thermit is supplied in welding portions accurately calculated to give a perfect weld on the size of pipe for which they are intended. A special mold is also required for each size of pipe. The

Fig. 60. Welding pipe lines with thermit at the Manhattan State Hospital for the Insane, Ward's Island, N. Y.

clamps are made in two different sizes, No. 1 being used for pipe up to 3 in. in diameter, No. 2 for pipe between 3 and 6 in. in diameter.

The pipe facing machine is made in two different sizes corresponding to the pipe clamps.

An important feature possessed by the thermit pipe welding process is the ease with which it can be applied to the welding of coils. The joints can be welded either before or after the pipes are bent.

Perfect welding reflects in costs

Give the man on the job Page Welding Wire and Electrodes and under his skilled handling uniformly perfect work will result.

And the man who handles costs knows where Page is specified as standard, the elimination of spoiled work and expensive delays reflects in added profit. *Page means better welding at less cost* because all Page wire and electrodes are processed to meet the exact requirements of the work to which they will be placed. They are shop tested to determine welding qualities—and each piece is plainly marked.

Write today for sample of wire and complete information.

PAGE STEEL AND WIRE COMPANY

Bridgeport, Connecticut

An Associate Company of the American Chain Company, Incorporated

District Offices:
Chicago New York Pittsburgh San Francisco

PAGE-ARMCO

PROCESSED

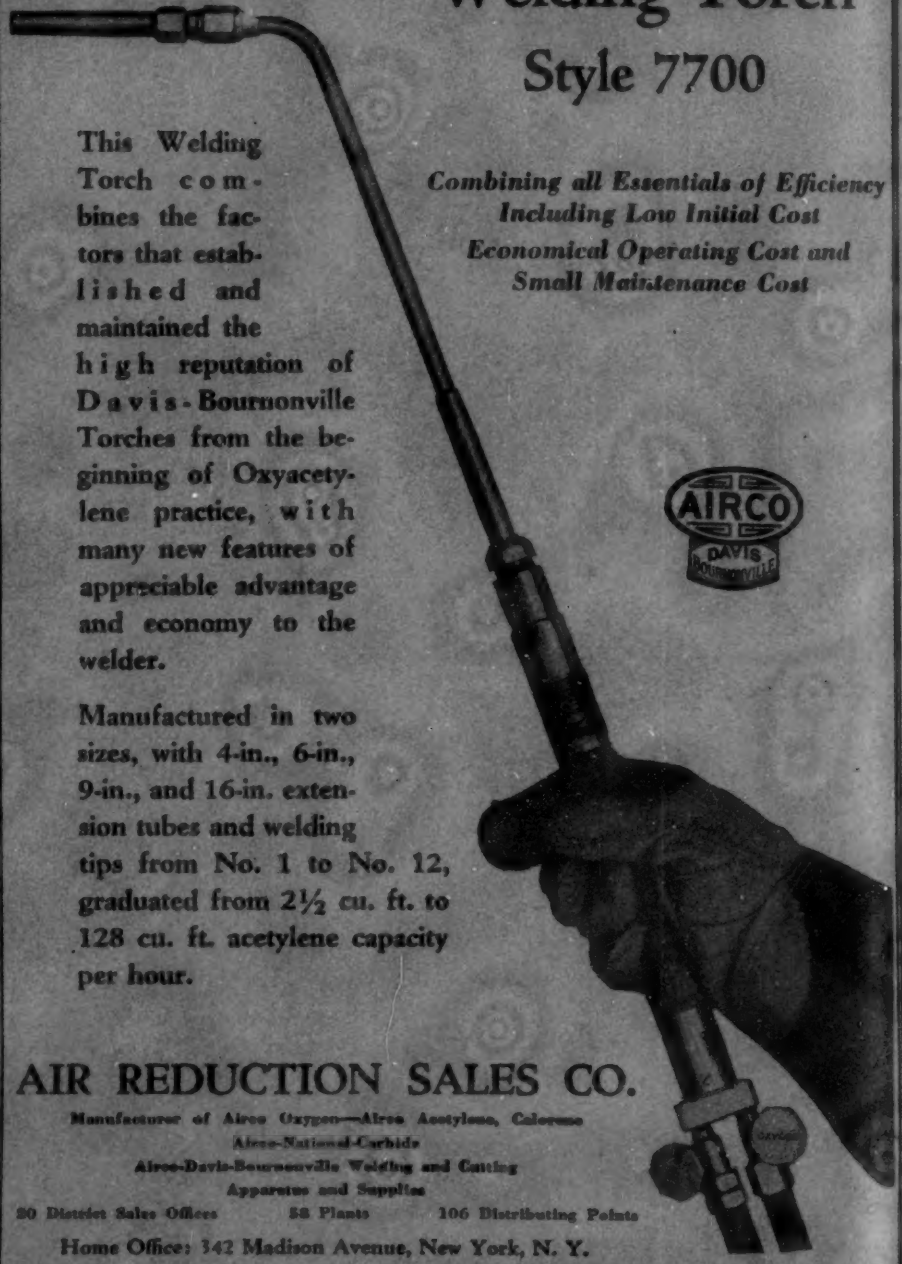
Welding Wire and Electrodes

An Airco-Davis-Bournonville

Welding Torch

Style 7700

Combining all Essentials of Efficiency
Including Low Initial Cost
Economical Operating Cost and
Small Maintenance Cost



This Welding Torch combines the factors that established and maintained the high reputation of Davis-Bournonville Torches from the beginning of Oxyacetylene practice, with many new features of appreciable advantage and economy to the welder.

Manufactured in two sizes, with 4-in., 6-in., 9-in., and 16-in. extension tubes and welding tips from No. 1 to No. 12, graduated from 2½ cu. ft. to 128 cu. ft. acetylene capacity per hour.

AIR REDUCTION SALES CO.

Manufacturer of Airco Oxygen—Airco Acetylene, Coleneo
Airco-National-Carbide
Airco-Davis-Bournonville Welding and Cutting
Apparatus and Supplies

20 District Sales Offices 58 Plants 106 Distributing Points

Home Office: 342 Madison Avenue, New York, N. Y.